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IN SEARCH OF A NEW CENTRALITY MODEL

Linking spatial network analysis, employment density and public transport networks in the city of London

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ABSTRACT

The paper can be read as an extension of previous studies on urban centrality. Using space syntax as a theoretical and analytical tool, the paper investigates the relationship between employment density, spatial accessibility and public transport, and how they each influences the understanding of urban centrality in the city of London. The general hypothesis of the research is that by linking spatial network, employment density and public transport, a more advanced model can be provided in understanding centrality in cities. Meanwhile, a more efficient methodology can be obtained for usage in urban planning and urban design. It is argued that both employment density and spatial accessibility are significant indicators of urban centrality. Spatial analysis is able to supplement and enhance the understanding of the employment-based centrality, which can be further enhanced by taking public transport system into consideration. In its search for a more advanced understanding of centrality, the study aims to develop a hybrid model of centrality that brings all of these influencing aspects into one single model. It is suggested that such a model is able to build an advanced profile of urban centres, which could serve as a tool to describe, evaluate and predict the centrality pattern of the city. This approach is proposed to be integrated in urban studies, urban design and urban planning processes for cities on various scales.

KEYWORDS

Urban Centrality, Employment Density, Spatial Accessibility, Public Transport System, Hybrid Model

1. INTRODUCTION

The issue of centrality is widely discussed in both urban economics and spatial studies. In a metropolitan city like London, centralities of different scales are emerging, developing and shifting all the time. Therefore, there is a need to look beyond a singly defined concept of centrality and look at how different aspects draw impact on the dynamic pattern of centrality and how they can re-define it.

This research aims to search for an advanced model in understanding urban centrality of London. The intention is to find out a tool that can describe the particular spatial and socio-economic features of centres. In doing so, this paper first explores the relationship between employment density, spatial accessibility, and underground network, and how they each influence the concept of urban centrality. On basis of these analytical results, attempts are made to integrate these elements into a hybrid model that can more accurately and specifically capture the centrality pattern of the city.

In Space Syntax literatures, numerous studies have already focused on the relationship between spatial configuration and socio-economic performance. This study serves firstly as continuation of these studies by investigating such a relationship on urban centres. Moreover, it attempts to establish a joint analytical model of centrality by combining both spatial data and socio-economic data. In other words, efforts are made in this paper in order to integrate the 'structural component with the phenomenological component' (Marcus 2007, p2) of urban centres. It is proposed that multiple measurements should be taken into consideration in one general model and it is believed that such a method would be of great value in urban planning and urban studies.

One of the common ways of identifying urban centres is to use the measurement of employment density, as it generally captures the economic vitality of an area. However, it is believed that such a method is not able to cover all situations. Therefore, this study brings Space Syntax analysis and public transport into discussion and attempts to find out how they are able to enhance the understanding of centrality. The general hypothesis of the research is that by linking spatial network, employment density and public transport, a more advanced model can be provided. Meanwhile, a more efficient methodology can be obtained for usage in urban planning and urban design.

On basis of the hypothesis, the first research question would be: How does spatial analysis enhance the understanding of urban centrality that is based on employment density? In order to answer this question, three sub-questions are investigated:

- To what extent is the measure of employment density able to identify urban centrality?
- To what extent is the measure of spatial accessibility able to identify urban centrality?
- What is the relationship between employment density and spatial accessibility and how does this relationship differ from centres to non-centres?

The second question is: How does underground network affect the concentration of employment and the emergence of centrality? Would it further enhance the understanding of urban centrality if taking public transport network into consideration?

With the above two questions, the third research question would be: If employment density, spatial accessibility and public transport network each has their role in understanding and identifying urban centrality, would a hybrid model integrating these aspects contribute to a more comprehensive understanding of urban centrality? If so, how should this model be built and how could it be applied to urban studies?

2. DATASETS AND METHODS

The study is conducted on the city of London within the M25 orbital. The analyses mainly use three sets of data: employment density calculated from Census data, spatial data obtained from street network model, as well as underground network, and the data on town centres from London Plan. The main platforms and software used in this study are: QGIS (geographic information system), space syntax analysis software Depthmap, and statistical analysis software SPSS (Statistical Product and Service Solutions).

Data/Measurement	Employment Density	Street Network	Public transport Network	Town Centres
Source	**National Statistics census 2011**	**Space Syntax Limited**	**TFL London**	**London Plan 2015**
Platform	QGIS	Depthmap & QGIS	Depthmap & QGIS	London Plan 2015
Statistical analysis		SPSS		/

Table 1 - Diagram of data and platforms used in the study

The main source of the employment data used in this study is from the Office of National Statistics census 2011 at workplace zones level. Workplace zone (WZ) is a new type of output geography for England and Wales used in census 2011. It has been produced using the workplace data as a supplement of the Output Area (OA) level. The OAs are designed to contain consistent numbers of people, based on where they live, while Workplace Zones (WZ) are designed to contain consistent numbers of workers, based on where people work. In this study, it is the employment situation of an area that is of interest, so Workplace Zones are considered to be more suitable for producing workplace-based statistics and outputs for further analysis.

The boundary of Workplace Zones of Greater London is imported into GIS platform. With the help of the built-in Python console, the employment data of each workplace zone is joined with the geo-referenced boundary using the ID of each WZ. Each of the 8154 workplace zones contains its geographic information as well as the number of employees that work in this zone. Employment density is then calculated as follows:

Employment density (hab/km2) = Population in employment within each workplace zone/ Area of that workplace zone *1000

This method generates a distribution pattern of employment density in London that can pinpoint the concentration of employment in this city. The measure is crucial for this study, and it also provides a relatively accurate method for the numerous research topics that concern spatial aspects of employment within other metropolitan cities.

Another dataset used in this research is the town centre network of London obtained from the London Plan 2015. London Plan is the overall strategic plan for London over the next 20–25 years. It sets out an overall framework that integrates economy, environment, transport and social life. Overall, 199 town centres are currently defined in the plan and are classified into four categories according to their existing roles and functions considering multiple criteria which include scale, mix of uses, financial performance and accessibility. The location of these town centres as well as their classification information are imported into GIS. In the study, the information of town centres network will serve as a reference of the current appearance of centrality of the city.

By importing all geo-referenced data into GIS, the spatial model, employment density model and town centre network model can be cross-analysed in one platform. In order to join spatial attributes of street segments with employment data of each workplace zone, each segment together with their spatial attributes are converted into its midpoint by using python console in GIS. Then these points are joined by spatial location with the workplace zones that they locate in. At the same time, the mean value of the spatial attributes, including Integration and Choice of R400, 800, 1200, 1600, 2000, 2400, 4000, 8000, 10000 and n, are calculated for each workplace zone. Through this approach, a statistic model is built, in which each workplace zone has its value of both spatial and employment data. The dataset is later imported into the SPSS software to build a linear regression model to analyse the correlation between employment density and spatial accessibility measured by Integration and Choice measurements. The same

method is applied again onto the second spatial model that contains underground network to see the difference.

3. RESULTS

3.1 EMPLOYMENT DENSITY AND TOWN CENTRES

Employment density is proposed to be a strong index of predicting centres. In the case study of London, the data of employment density is plotted onto 8154 Workplace Zones in GIS. The employment density data has a skewed characteristic. Areas with high employment density concentrate only in a small part of the city. The highest employment density areas concentrate in the main centre of London along Oxford Street. Other sub-centres of employment are dispersed radially around the centre.

By overlapping town centres with employment centres, it can be seen that employment density and the location of town centres have a strong correspondence. Due to the skewed nature of the dataset, areas with the top 40% value of employment density can be seen as employment centres. Statistically, among the 199 defined centres, 33 of them locate at the top 20% of the employment density value, and 149 of them in total locate at the top 40%, which means that 91% of the town centres are also the places where employment activities aggregate. Therefore, it can be concluded that in the city of London, the measurement of employment density is a strong predictor of centrality.

However, there are still examples of non-correspondence between the two. Some areas such as Park Royal and St George's hospital are with high employment density but they are not serving as town centres. Most of these areas are industrial areas, large clusters of offices and factories, large hospitals, schools and government institutions that offer high number of job opportunities. In contrast, some town centres such as Harold Hill and Coller Row are found to have low employment density, and most of these centres are suburban towns located in the periphery of London and serve as local centres of their surroundings. This suggests that although employment density is seen as a strong predictor of centres, it cannot cover all conditions.

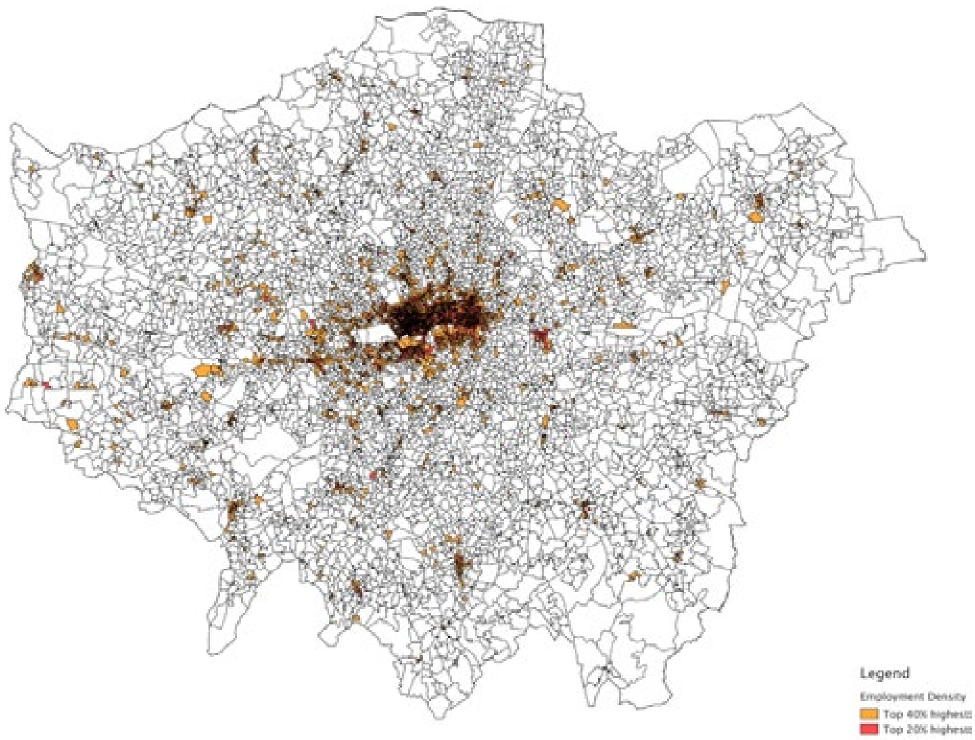


Figure 1 - General pattern of employment density in London

3.2 SPATIAL CONFIGURATION AND TOWN CENTRES

Numerous space syntax literatures have shown how spatial configuration is related to centrality. Space syntax measure of 'Integration' is commonly considered as a measure that implies centrality of an area, which closely associates to the emergence of town centres (Hillier 1999). The higher the integration value is, the more central and closer is the space to all spaces within the network. It is suggested that higher spatial accessibility is associated with higher amount of pedestrian movement. The movement economies generate better economic performance of the area, thus lead to the emergence of urban centres (Hillier 1996). Here in this research, by overlapping the town centres with various spatial analyses, the correspondence between the two can be clearly seen from the pattern. Figure 2 suggests that Normalized Angular Choice Rn corresponds quite well with the location of town centres. Except for some small district centres, most of the centres lie on the highest choice value segments. Global Choice is thus indicated to be an important value for predicting centrality. Also, normalized integration in various radii can be used to identify centres of different scales. Integration Rn picks up centres in central London as well as those in the 'wheel spokes' (Hillier 1989) that connect the central area to the edges of the city. Integration R800 picks up centres that are locally integrated. It is able to identify those district centres that serve local communities. Besides single measures, spatial attributes in multiple scales can be combined in order to identify centres with specific features. For example, Figure 3 shows the pattern of added value of Normalized choice R800, R2400 and R8000. The pattern then can be used to identify areas that have either distinct global centrality or local centrality. In the same way, multiplied measure of normalized integration R800, R2400, R8000 can identify centres that are both locally and globally integrated (Figure4). Particular measures can be formulated according to the requirements of urban analyses.

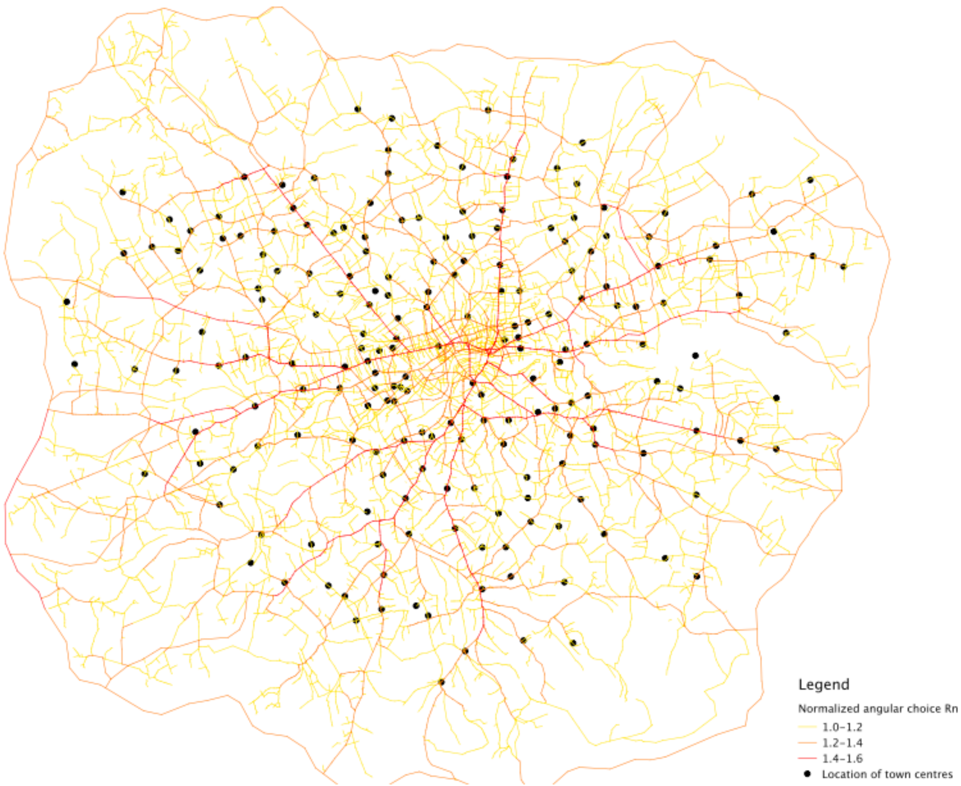


Figure 2 - Location of town centres and global choice

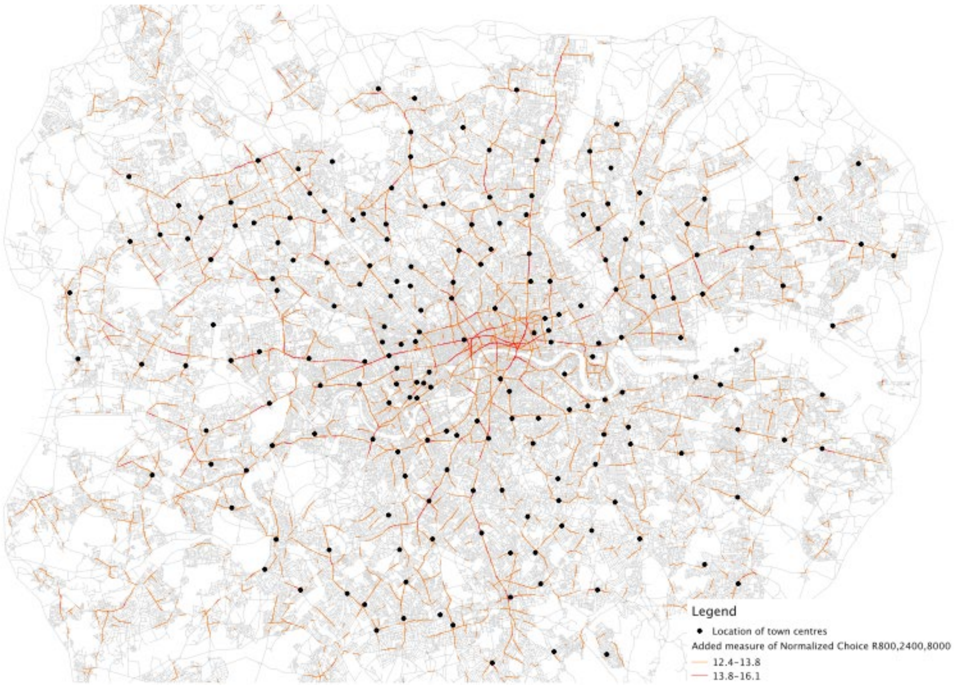


Figure 3 - Added measure in identifying centres either global or local

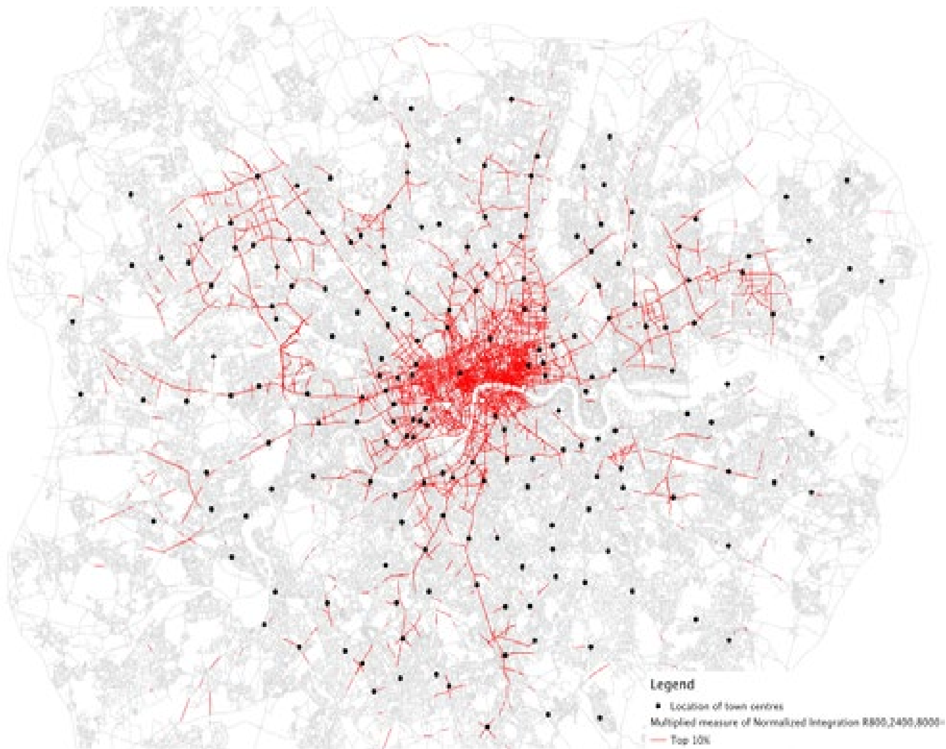


Figure 4 - Multiplied measure in identifying centres both global and local

The spatial characteristics can be further studied exclusively for centres. One can establish a spatial profile of centres by creating a buffer of radius 800 metres for each centre, and joining their spatial attributes with the buffers (Figure 5). There is one exception for the centre of West End. As it covers almost the entire central area of London, a larger buffer of 2000 metres has been created for this specific case. With the spatial profile, it is easy to rank these centres according to their spatial attributes and use this as a tool to distinguish the spatial accessibility of centres and accordingly predict their socio-economic performances. As an example, Table 2 lists the top 20 centres ranked by normalized choice and normalized integration in combined radii. With the above analyses, it is evident that spatial accessibility measured by integration and choice is also a powerful tool in identifying urban centrality. It is more flexible in terms of catching centres of various scales and particular features.

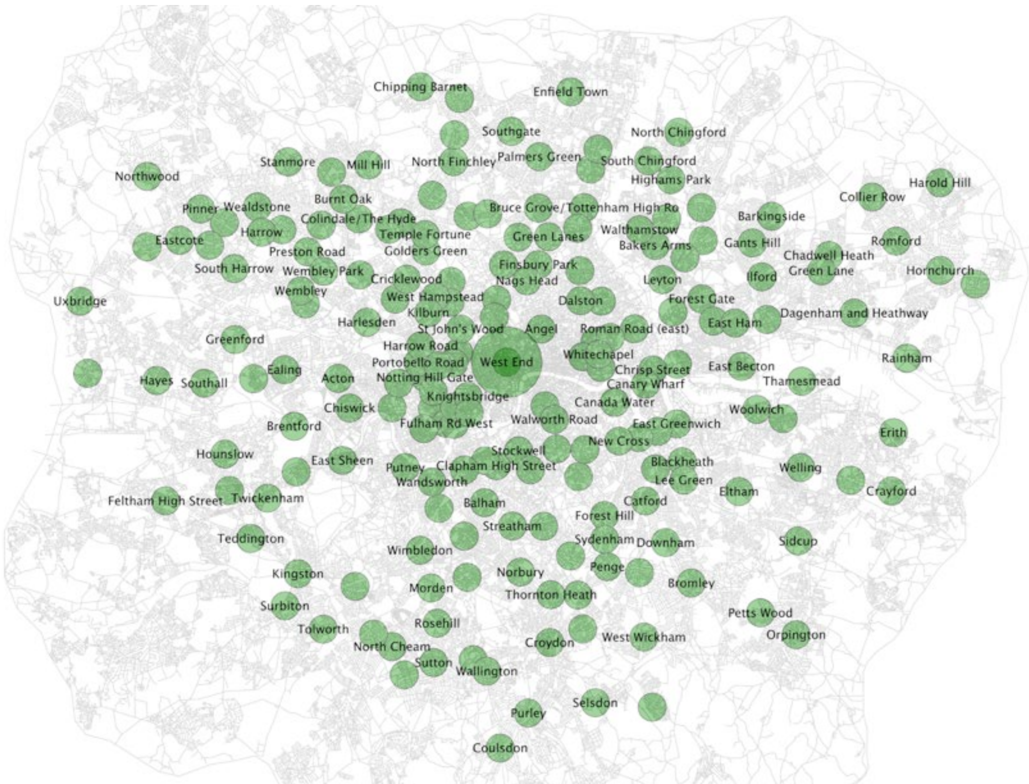


Figure 5 - Buffers of centres with spatial attributes

Rank	Centres ranked by NACH (R800+R2400+R10000)	Centres ranked by NAIN (R800+R2400+R10000)
1	Dalston	West End
2	Dalston	Brick Lane
3	Ilford	Dalston
4	Brick Lane	Angel
5	Clapham Junction	Elephant & Castle
6	East Ham	Pread St / Paddington
7	Pread St / Paddington	Bethnal Green
8	BakersArms	Edgeware Road/Church St
9	Gants Hill	Clapham Junction
10	Edgeware Road/ Church St	Whitechapel
11	Kingston	Shepherds Bush
12	Leytonstone	Stockwell
13	Tooting	Mar e Street
14	Angel	Knight sbridge
15	Stoke Newington	Brixton
16	Knightsbridge	Queensway / Westbourne Grove
17	Palmers Green	Camden Town
18	Mare Street	Notting Hill Gate
19	King's Road East	Ilford
20	Streatham	Clapham High Street

Table 2 - Centres ranked by spatial attributes

3.3 RELATIONSHIP BETWEEN EMPLOYMENT DENSITY AND SPATIAL ACCESSIBILITY

This section explores the relationship between employment density and spatial accessibility, and how this relationship differs between centres and non-centres, and more specifically, between centres in central London and those in outer London.

Figure 6 reveals a general pattern of association between employment density and Choice values. The visual result shows clearly that, spatial accessibility centres and employment centres have a significant correspondence. To further investigate the correspondence, a statistical model is built, which includes both employment density and spatial accessibility data for all Workplace Zones. The dataset is imported into SPSS in which a linear regression analysis is carried out between employment density and spatial accessibility. In the regression model, the value of Ln (employment density+3) is defined as dependent variable while Integration and Choice value from R400 to R10000 are set as independent variables and are tested against the dependent variable respectively. Statistical analyses have proved that employment density has significant correlation with both Angular choice and Angular Integration in various radii. The overall correlation with Integration is considerably higher than that with Choice, and thus Integration measure will be used in further comparisons between models.

Table 3 records the R-squared value in each radius tested. For the entire model, the correlation is significant in all scales and has high R-squared values from 0.467 to 0.631. The highest R-squared appears at meso scales from R1200 to R4000, and is slightly lower at micro and macro scale. In terms of centres only, the correlation between employment density and Integration value is also significant, ranging from 0.416 to 0.712. There is a dramatic increase in the R-squared value of centres compared to the entire model from R400 to R2400, and it starts to decrease for larger radii. This suggests that the Integration value of micro and meso scales correlates better with employment density in centres.

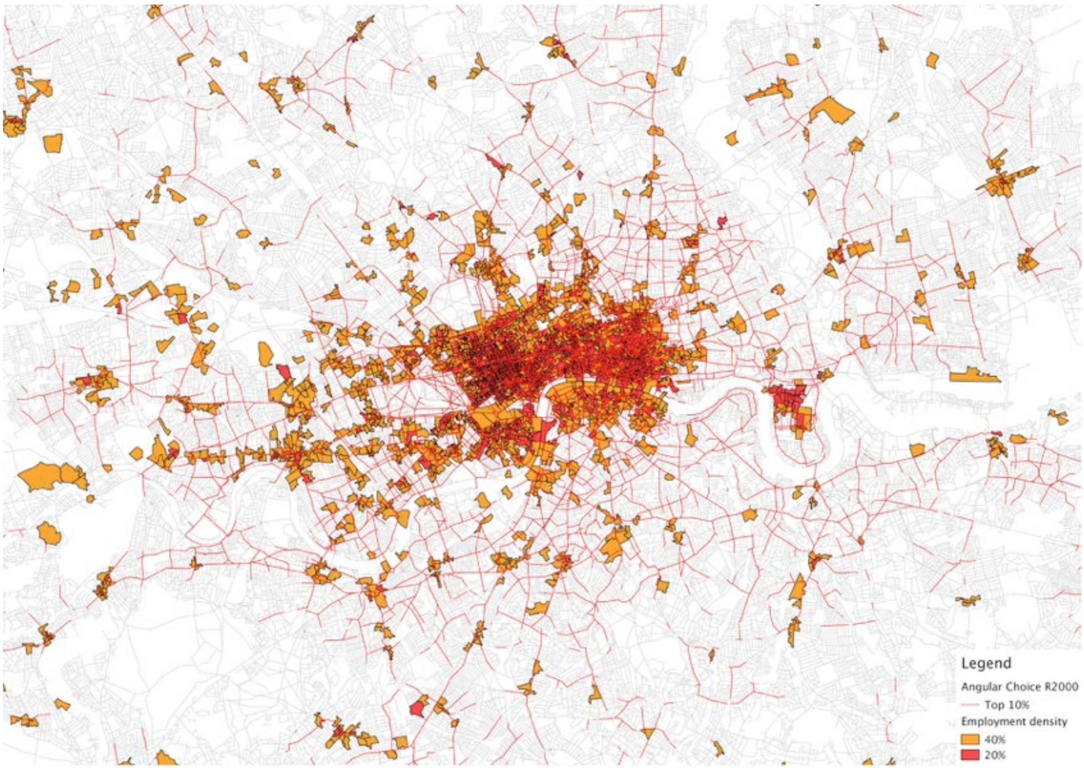


Figure 6 - General correlation between areas with high employment density and high choice value

R-squared value between Ln (employment density+3) and Integration

Radius	Entire model	Centres
IN R400	0. 485	**0. 712**
IN R800	0. 572	**0. 720**
IN R1200	0. 610	**0. 711**
IN R1600	0. 626	**0. 697**
IN R2000	0. 630	**0. 682**
IN R2400	0. 631	**0. 665**
IN R4000	0. 630	0. 615
IN R8000	0. 591	0. 582
IN R10000	0. 563	0. 550
IN R	0. 467	0. 416

Table 3 - Correlations of the entire model and centres only

To further investigate this relationship, centres that located in the central London are distinguished from those in outer London. It is believed that these centres might have distinct performance than others due to their distinguished location. In this study, centres locate in central areas are separated from dataset and their spatial attributes and employment density are analysed again separately.

The results are recorded in Table 4. Statistical outputs reveal an even higher correlation between employment density and spatial integration for these centres. The increase again occurs from R400 to R2400 where the R square values reach the highest number of 0.706 to 0.824 respectively. With such results, it seems possible to suggest that the more central the areas are, the higher correlation exists between employment density and integration. In other words, the result indicates that spatial accessibility can capture better the employment agglomeration in the central areas of the city than the peripheral areas.

R-squared value between Ln (employment density+3) and Integration

Radius	Centres	centres in central London
IN R400	**0. 712**	**0. 416**
IN R800	**0. 720**	**0. 824**
IN R1200	**0. 711**	**0. 824**
IN R1600	**0. 697**	**0. 801**
IN R2000	**0. 682**	**0. 764**
IN R2400	**0. 665**	**0. 706**
IN R4000	0. 615	0. 546
IN R8000	0. 582	0. 554
IN R10000	0. 550	0. 444
IN R	0. 416	0. 109

Table 4 - Correlations of all centres and centres in central London

3.4 INCORPORATING THE UNDERGROUND NETWORK AND MEASURING ITS INFLUENCE

As stated before, the underground network is considered to have its impact on the emergence of centres. In order to test such impact, a new spatial model is created in Depthmap that incorporates underground network into street network of Greater London.. Lines taken into consideration include eleven London underground lines, London Overground line, Docklands Light Railway and Crossrail. All stations are geo-referenced according to London underground map from TFL. With reference to Law's methodology of building a bi-model (Law et al. 2012), a line is drawn from each station to the street network model at about 90 degrees, which represents the cost of entering and exiting the station. Using the link function in Depthmap, each trip between stations is linked directly (Figure 7). With this method, the two independent networks are linked in one model. The new model with links between stations is then converted into axial and segment maps for analyses. The results are then imported back into GIS for further comparisons with other data. One thing to note is that the method is in its experimental stage and the optimization of the model is not the priority of this paper. Instead, a simplified way is adopted in this study to explore the trend.

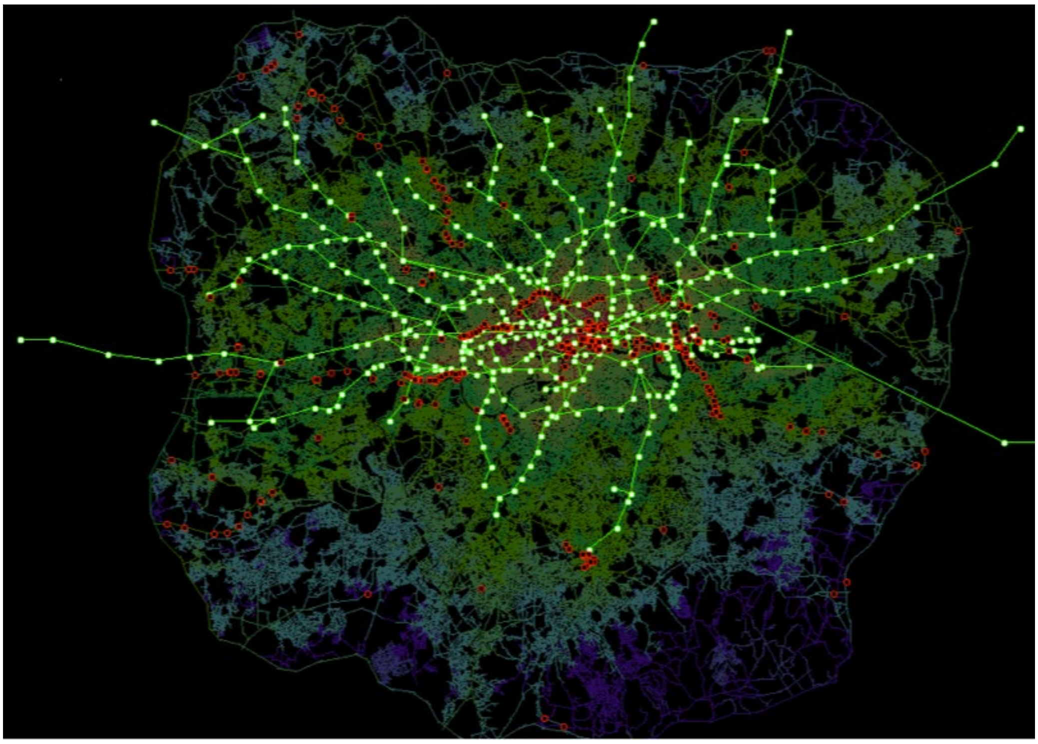
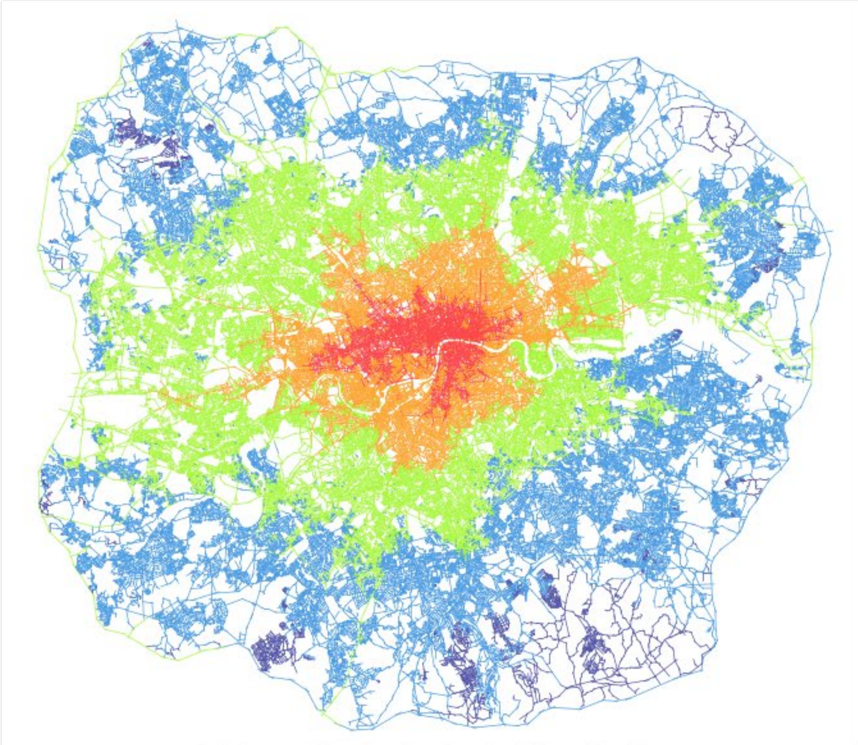
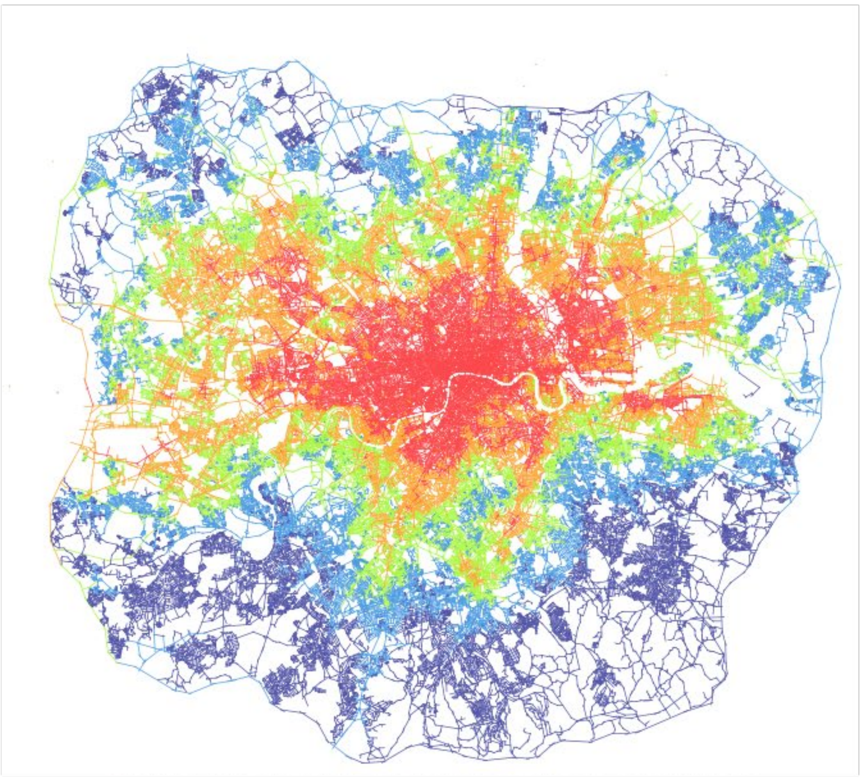


Figure 7 - Method of integrating underground network into street network model

With the results of the analysis for both street-only network and the combined network, it is straightforward to compare the two models and see how underground network influences the spatial configuration of the city. Figure 8 presents the global Integration value mapped on two axial maps. The upper image shows that of street-only network and the lower one the combined network. The impact is quite clear from the map. Generally speaking, in the new model, the strong central core is still maintained, but it expands along the underground network and reaches further to the periphery of the city. The central core is strengthened and enlarged due to the dense transport network in and around it. New centralities emerge in the south of river Thames, where many areas are considered to be far from central London without public transport. Another new emerging centre that can be observed in the map is to the east of the central area around Woolwich and Plumstead. The overall comparison demonstrates two main features of London underground and rail network: firstly, it covers most part of the city and brings the periphery to the centre; secondly, it generally follows the centralised structure of street network and strengthens the central core. Further comparison is made between two segment models. In order to visualize the impact, a difference map is created by calculating the difference of spatial values on each segment line of two models. Figure 9 presents the difference map of Integration R8000 between two segment models. Segments with red and yellow colours mean that their integration values are increased in the combined model, and segments with green means the value is slightly decreased. Those with grey colour stay almost the same value in two models. Firstly, it can be observed that there is great improvement in South London along the underground Circle Line, including areas such as Croydon, Penge, Forest Hill and Dulwich. Several centres in this area are largely dependent on the underground network to be linked with central London. Secondly, strong impacts are found at some transportation junctions where two or more transport lines intersect. Areas like Canary Wharf, Westham, Archway and Paddington become more integrated into the city network with the underground system.



Axial map_Street network only_ Integration Rn



Axial map_Street network +Underground network_ Integration Rn

Figure 8 - Comparison between two axial models

Figure 9 - Difference map of two models

The difference shown in spatial analyses gives rise to an intuitive hypothesis that in the case of London, the underground network casts influence on urban centrality. In order to test whether a hybrid spatial model including underground network can enhance its ability in predicting socio-economic performance of the city, the correlation between employment density and spatial accessibility is calculated once again in the hybrid model. Table 5 shows the results from linear regression analysis between Ln (employment density+3) and Integration value in various radii. Comparing the entire hybrid model with the street-only model, the correlation between employment density and integration is improved in meso scale, from R800 to R2400. While at micro and macro scale it almost stays the same or even drops a bit. Results suggest that the combined spatial model can slightly enhance the prediction of employment centres in meso scale, whereas at micro and macro scale it does not make much difference. The improvement is not quite significant and only shows a trend. It is possibly because the underground network in this analysis is not weighted by the magnitude of origins and destinations for each station when being integrated into the street network model, making its influence underestimated in the results.

R-squared value between Ln (employment density+3) and Integration

Radius	Entire street model	Entire hybrid model
IN R400	0. 485	0.485
IN R800	0. 572	**0.577**
IN R1200	0.610	**0.622**
IN R1600	0.626	**0.641**
IN R2000	0.630	**0.647**
IN R2400	0.631	**0.647**
IN R4000	0.630	0.628
IN R8000	0.591	0.584
IN R10000	0.563	0.550
IN R	0.467	0.467

Table 5 - Compare correlation between two models

R-squared value between Ln (employment density+3) and Integration

Radius	Centres street model	Centres hybrid model
IN R400	0. 712	0.707
IN R800	0. 720	**0.721**
IN R1200	0.711	**0.717**
IN R1600	0.697	**0.703**
IN R2000	0.682	**0.688**
IN R2400	0.665	**0.671**
IN R4000	0.615	**0.617**
IN R8000	0.582	**0.586**
IN R10000	0.550	**0.551**
IN R	0.416	**0.433**

Table 6 - Compare the R-squared of centres in two models

However, the improvement is interestingly much more consistent when comparing the same value for only centres in two models (Table 6). Using the spatial analysis of the hybrid model, the spatial and employment data have been applied to buffers of each centre. Linear regression analysis is conducted again on centres only and the values of R-squared are recorded for each scale. Similar to the street network model, the R-squared values appear approximately between 0.5 and 0.7, which means that the space syntax measure of integration can explain more than 50% of employment density data. The comparison shows that the correlation between employment density and integration is higher in the hybrid model than street-only model. This improvement occurs in all scales except for a tiny drop in R400. It suggests that the hybrid spatial model is able to capture more accurately the employment concentration in centres than in non-centres. In other words, the impact of underground network on employment density is considered to be more significant in centres. This indicates an idea that the hybrid model that takes public transport into consideration may be a more accurate model especially in studying urban centrality.

3.5 THE HYBRID MODEL: SEARCHING FOR A STRATEGIC PLANNING TOOL USING A COMBINED MEASUREMENT OF URBAN CENTRALITY

As learned in previous sections, both employment density and spatial accessibility are strong indicators of urban centrality. To simplify, one can say that the former represents one crucial aspect of socio-economic centrality and the latter the spatial centrality. In reality, the real condition of urban centrality is complicated and has multiple facets. Although it is effective to use one set of socio-economic data or spatial model in predicting or describing centres, none of them is able to capture the full picture of urban centrality. An attempt is conducted in this section towards a more comprehensive centrality model. As proved, employment density, spatial accessibility and public transport network each has their weight in understanding and identifying urban centrality. Bearing in mind such conclusion, a new hybrid model is built for the city of London, which combines both employment and spatial data, optimised by adding transport network. This attempt implies the idea that urban centrality is not a one-fold concept. Deeper knowledge would be achieved if it can be described with multiple aspects that contribute to its emergence.

This section explores several possibilities of applying the hybrid model into identifying new classifications for centres and profiling centres based on their core characteristics.

The first stage of building a hybrid model is to put both spatial data and socio-economic data into a single platform. In this study, as each centre buffer is assigned with its spatial attributes and employment data, it is easy to identify both the correspondence and non-correspondence between the two attributes within one model. At this stage, such a model is a useful tool for describing distinct features of centres separately and accurately. It can act as straightforward way to find out areas with non-correspondence between different aspects of centrality. Table 7 lists examples of the centres of four different categories: centres that have high values in both attributes are mainly located in the central part of London; centres that have low values in both are mainly new towns or district centres located in the periphery; centres that have high employment density but low spatial accessibility include Uxibridge, Romford and Woolwich; and centres with low employment density but highly accessibility include Palmers Green, Norbury and North Harrow. This classification offers another way of analysing centres and describing their socio-spatial performance. It provides a simple way of identifying areas with non-correspondence between spatial centrality and socio-economic centrality. And these areas are likely to have high potential for further development.

Employment Density	Spatial Accessibility	Example of centres
High	High	Brick Lane, West End, Tooting
High	Low	Uxibridge, Romford, Woolwich
Low	High	Palmers Green, Norbury, North Harrow
Low	Low	Erith, Rainham, Northwood

Table 7 - Examples of centres in four situations

Except for describing distinct features separately, a further step can be made by using the model to create a hybrid measure, which is able to describe the overlapping of these features. With both spatial and employment data plotted on each workplace zone, the hybrid measure can be calculated by multiplying these values. In this study, a hybrid value is calculated as below:

$$\text{Hybrid value} = (\text{NAIN R800} + \text{NAIN R2400} + \text{NAIN R10000}) * \ln(\text{employment density} + 3)$$

The map in Figure 10 presents the distribution of the hybrid value. The spatial accessibility is based on the spatial model that takes underground network into consideration. It uses the mean value of Normalized Integration R800, R2400 and R10000 to cover all scales. The areas picked up by this hybrid measure are meant to have both high employment density and high spatial accessibility in all scales. Interestingly, when the results are compared with the location of town centres defined by London Plan, almost all of these areas are classified as 'metropolitan centres', which are defined as places that serve wide catchments and have high accessibility and significant levels of employment, service and leisure functions. The only exception here is Canary Wharf. It is picked up by the hybrid measure, as the area is extremely strong in employment density value and also strong in spatial accessibility when including public transport. Although it is defined as major town centre, the performance of the area fits the description of the hybrid measure. This indicates that the current classification of centres may change as time goes by, according to the performance of the area. The hybrid model and its targeting measurement would be of help in re-classifying and multi-classifying centres with accuracy.

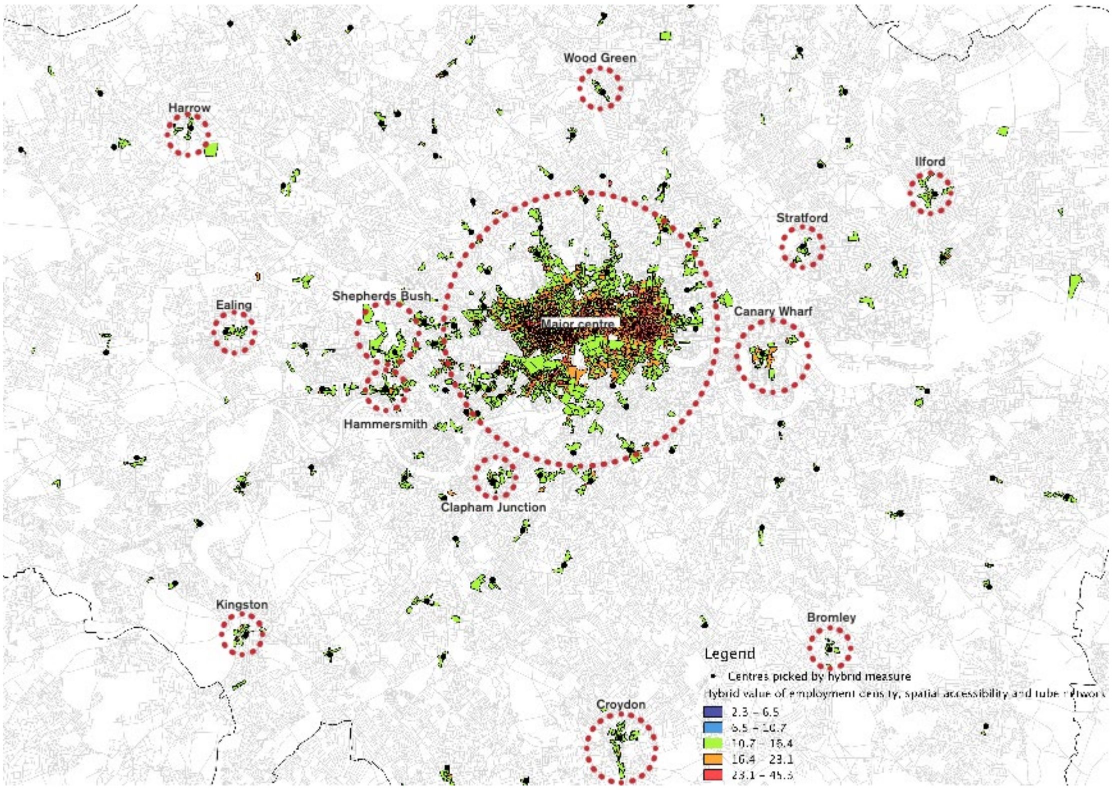


Figure 10 - Centres picked by hybrid measure of employment density, spatial accessibility and underground network

The examples in previous sections have primarily shown the advantages of building a hybrid centrality model for the citywide area of London. Not only does it provide a more comprehensive method of identifying centrality of the city, but it also creates a full socio-spatial profile of existing centres. In the hybrid model, each centre is given both spatial data and socio-economic data. As a result, centres can be described by either a single aspect or multiple ones. Rather than the classifications provided by London plan that define centres into metropolitan, international, major and district ones, a much more detailed and flexible classification can be offered by the hybrid model. A hybrid measurement that combines employment density, spatial accessibility and public transport network can be calculated for each centre. Table 8 illustrate the centres ranked by the hybrid measure as defined in the last section. With the measurement, a new hierarchy of these centres can be built and applied in urban planning as an important reference

for development decisions. In other words, the hybrid model acts as a tool to firstly, describe the performance of centres; secondly, evaluate the importance and hierarchy of centres and lastly to discover and predict the potential of them.

Rank	Name of centres	NAIN (R800+2400+10000)	Employment Density Ln (ED+3)	Hybrid	Value
1	West End	4. 999762753	47. 92670978	3. 930387536	19. 6510052
2	Brick Lane	4. 873527789	43. 27576025	3. 834618287	18. 68811878
3	Edgewar e Road / Church St	4. 296783788	16. 82816751	2. 987103528	12. 83493801
4	Pr ead St / Paddington	4. 42402942	13. 54045728	2. 805809336	12. 41298304
5	Angel	4. 59089987	11. 60504617	2. 681367097	12. 30988785
6	Knightsbridge	4. 146570556	16. 43486534	2. 967068635	12. 30315943
7	Canary Wharf	3. 39078187	29. 873896	3. 492678922	11. 84291236
8	Elephant & Castle	4. 460331833	9. 664838127	2. 538829502	11. 32402204
9	Shepher ds Bush	4. 184838316	11. 60830179	2. 681589983	11. 2220205
10	Fulham Rd East	3. 929099126	13. 6677507	2. 813475757	11. 05442513
11	South Kensingt on	3. 934210047	11. 52117593	2. 675607993	10. 52640384
12	Camden Town	4. 105835073	9. 733119946	2. 544206469	10. 44609215
13	Queensway / Westbourne Grove	4. 113583905	9. 628452231	2. 535952382	10. 4318529
14	Ki ng' s Road East	3. 957823706	10. 25055724	2. 584039608	10. 22717321
15	Whitechapel	4. 213175221	7. 821403392	2. 381525968	10. 03378619
16	Chrisp Street	3. 270737175	15. 77311654	2. 932425875	9. 591194322
17	Fulham Rd West	4. 043208561	7. 70024105	2. 370266269	9. 58348087
18	Earls Cour t Road	3. 766384297	9. 363577886	2. 514754883	9. 471533302
19	Dalston	4. 716366801	4. 361931051	1. 996322269	9. 415388073
20	Kensingt on High Street	3. 886315184	8. 057984172	2. 403152717	9. 339408893

Table 8 - The top 20 centres ranked by hybrid measure

4. CONCLUSIONS

To summarize, the findings of the study suggest that both employment centrality and spatial centrality are significant indicators of urban centrality. Spatial analysis is able to supplement and enhance the understanding of centrality that is purely based on employment density, and it can be further enhanced by including public transport system into the spatial model. Therefore, a hybrid centrality model is proposed. An overall model that combines employment density, spatial accessibility and underground network is created for the city of London. It is suggested that the hybrid model is advantaged in identifying both the overlapping and non-correspondence between spatial and socio-economic centrality. It builds a full profile that can describe centres with more specific characteristics and is thus of great use in urban planning and urban decisions.

One contribution made by this research is that it provides a methodology for applying census data in large scales to spatial studies with a satisfactory level of accuracy. In the situation where detailed social-economic data are sparse and incomplete, it is an efficient approach to use census data and spatial analysis to evaluate the pattern of centrality. This research has used a method that joins spatial data with socio-economic data based on census boundary, by simplifying street segments into points that carry with all spatial attributes and calculating the

mean values of the spatial attributes for all points that fall in the boundary of each workplace zone. This methodology manages to take advantage of the vast range of census data on a relatively detailed level. The output offers a feasible way to relate spatial analysis with many other aggregated data and is especially useful in urban-scale studies.

Another virtue of this research is that it provides in-depth analyses on centralities identified by multiple aspects. The study has shown that through building a hybrid centrality model, a better understanding of urban centrality and the performance of centres can be obtained. The hybrid model provides a measurement that constitutes considerations on spatial accessibility, employment density and public transport. The measurement should be considered as a starting point for viewing centrality from multiple aspects. In the era of Big Data, spatial configuration models, census data and many other socio-economic data are easier to obtain and should be properly exploited. It is important to note that this study is not trying to imply that always the maximum level of information should be considered in the model. It is more about suggesting that, when needed, a more comprehensive model of centrality could be built with consideration of the aspects that are important and can enhance the final output. The value of the hybrid model does not lie in adding yet another measurement, but in applying space syntax analysis into a broader context, where multiple actors can work interdependently in one model, just as it is done in real urban systems. Such a model is proposed to be more clarifying and more useful for future urban planning and urban economic studies as, well as a tool for strategic and investment decision-making.

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