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SPATIAL IMPACT OF NEW PUBLIC TRANSPORT SYSTEM ON STATION NEIGHBOURHOODS

The cases of Jubilee Line Extension in London

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ABSTRACT

The implementation of a new public transport system is considered to have a significant impact on the flow of people and economies in cities and towns. Though, spatial configuration that could stimulate urban growth has yet to be clearly identified in transport and urban studies. The new public transport services are believed to increase transport network accessibility and facilitate daily commute. In the transport system, stations could be the "nodes" that enhance the transport integration by providing connection for flows of people and goods, as well as be the "places" where they emerge within urban fabric to support the diversity of socio-economic activities. In this regard, the objective of this study was to verify the spatial impact of new public transport systems, with particular attention paid to the neighbourhoods surrounding stations, to identify whether stations are embedded in better locations to optimise urban regeneration.

This study focused on the latest implementation of the London Underground system, the Jubilee Line Extension (JLE) which connects Central London to the East and South-east London. Four neighbourhood stations along the JLE (Bermondsey, Canada Water, Canning Town, and West Ham) have been analysed in this study. By applying space syntax theory and tools, this study accessed both qualitative and quantitative spatial analysis with demographic and land use data. The results revealed that the location of stations, in terms of the configurational urban network, would be a factor in optimising socio-economic development in the station neighbourhoods. It also suggested that space syntax could be an effective analytical methodology used to understand the relationship between transport network and urban morphology for future studies in land use and transport planning.

KEYWORDS

Spatial Configuration, Public Transport, Urban Morphology, Station Neighbourhoods, Network Accessibility

1. INTRODUCTION

Urbanisation is a process of human settlement which shifts people from rural areas to cities. The extensive systems of metropolis are meant to facilitate interaction between people and support social and economic activities. With populations rapid growth, maintaining the equilibrium of social and environmental sustainability and the rise of densification in the city centre has become more challenging. Housing, education, health care, energy consumption, transportation, and environment are some of the critical issues brought about by urbanisation. Transport development, however, might be a standout among these issues. This is because all the urban activities rely on transport networks to provide the connection for interaction, as face-to-face meetings remain fundamental to sustaining everyday life. Enhancing the mobility to travel between locations of urban activities through various modes seems to be the right strategy to improve the living conditions in metropolitan areas. Therefore, it is clear that most large cities need a more efficient and convenient transport network to support the increasing travel demand and to improve the commutes between different urban activities. Moreover, a better transport network could relieve the high density in the city centre and potentially integrate with multiple aspects of urban development.

The majority of transport planning in major European cities was devoted to promoting public transport over vehicular transport. Public transportation is considered to be a more sustainable transport system reducing air pollution, traffic congestion and energy consumption. It is also regarded as a safer and cheaper mode of transport. With this in mind, this study focused on the influence of rail-based public transportation systems on urban activities, by investigating the interrelationship between urban contexts and the accessibility in both of transport and street network. It will also aim to portray how spatial configuration can shape the local urban development.

Empirical studies demonstrated that network accessibility is influenced by the transport system and directly impacts the distribution of land use locations (Hansen, 1959; De La Barra, 1989; van Wee, 2002; Geurs et al., 2004). Additionally, the characteristics of the locations support different urban activities and generate the necessity of travel between spaces which eventually requires upgraded transport systems. This phenomenon could be explained by the transport land use feedback cycle (Wegener, 2008; Bertolini, 2012). It indicated that network accessibility is the key to develop a transport system, not only by its effect on travel behaviour but also on how urban context influences the level of accessibility. In geographic and economic studies, accessibility represents the relative proximity of one place to all other places based on the distance to other locations in the network, and the opportunity for activities in those locations (Hansen, 1959; Batty, 2009). It can be applied to measure the spatial distribution and connectivity within transport networks, and links travel patterns together with land use and socio-economic variables. In urban study, accessibility is also an urban form indicator used to access the interaction between street layout, transport network and land use patterns in multi-scales (Gil, 2016). Previous studies showed that locations with higher degrees of accessibility have a better chance of being developed with a higher density population and mixed land uses (Hansen, 1959). Measuring accessibility, therefore, can be used to understand the global and local impact of transport system on cities and towns.

Traditionally, studies in transport planning and engineering presume the transport networks are equilibrium systems by applying algorithms and mathematical programming methods to predict the flow and capacity between links and nodes. The analysis is based on the cost effect of the space-time network and intent to optimise results in transport development (Daganzo, 1997; Bell et al., 1997). It ignores the extensive, long-term impact of the implementations on the global and local environment which could cause irreversible damages in the quality of urban life. On the other hand, studies in urban planning and morphology seem to consider accessibility simply as one of many concerns, rather than a central, structuring perspective in the development of cities (Bertolini, 2012). There is clearly a gap between transport and urban study on the integration of transport systems with the urban context and environment. Most transport and urban research relate to public transport systems emphasising the capacity and accessibility within the network. Stations are generally recognised by their function as nodes of transport hubs or the expansion of retail centres. With this trend, planners and engineers adopted the Transit-Oriented Development (TOD) as a primary strategy in urban and transport planning. With the emphasis on the function of the transport infrastructure associated with land values and commercial or residential development, particularly in the station neighbourhood. Less attention has been given to spatial emergence of transport interventions, to the urban fabric and the network accessibility effects on employment and inhabitants.

For the public transport interventions, Bertolini suggested that stations as 'nodes' increase transport integration and provide the connection for material and immaterial flows within the networks. On the other hand, stations can also be 'places,' where they emerge and grow within the urban fabric and support the diversity of urban life (Bertolini, 1996). The implementation of public transport systems and the embeddedness of stations could generate local centrality which intensifies socio-economic activities with better accessibility. At the same time, the intrusion of infrastructure could present spatial segregation that distorts the urban environment and impede urban regeneration. These associated phenomena are spatial effects which relate to the structure of urban layout rather than specific attractors. Thus, the design and implementation of public transport systems require the understanding of spatial effect which relates to the urban form and accessibility (Karimi, 2012). The objectives of this study are to verify the spatial impacts on station neighbourhoods and identify the spatial conditions to examine whether stations are embedded in the best location for optimising urban regeneration.

Space syntax encompasses a set of urban theories and methodologies for investigating the relationships between spatial layouts and a range of social, economic and environmental phenomena (Hillier, 1989). Studies have applied space syntax methodology to examine the accessibility effect of the public transport network. Previous research indicated that spatial configuration dominates the commuters' behaviour above ground in the urban street network but topological configuration affect the ridership in underground transport networks (Chiaradia, 2005). On a global scale, the invention of public transport system could shift the accessibility of street network with the topological effect of the public transport services (Schwander, 2007). This phenomenon has been studied by multi-modal analysis which integrates the public transport network with the urban street network (Gil, 2012; Gil,2014; Law et al., 2012). However, the spatial effect of station neighbourhoods, as well as the location of stations and how this could accelerate or hinder the development, has not yet received much attention. The spatial analysis of London Kings Cross Station neighbourhood in the Natural Movement study (Hillier et al. 1993), has demonstrated that the infrastructure of railway stations would affect urban street networks in connectivity and accessibility which could generate or interrupt pedestrian movement patterns. Bolton, in the study of railway terminus neighbourhoods in London, also suggested that the location and spatial characters of a station would influence pedestrian movement and the development of urban structure over time (Bolton, 2015). The spatial integration of stations with existing urban environments have been investigated by space syntax analysis with socio-economic variables and demonstrated that spatial conditions bring impacts on the distribution of land use and the walkability around station neighbourhoods (Mulders-Kusumo, 2005: Dhanani and Vaughan, 2016).

Following the (1) introduction, this paper will present (2) the background of the case study, (3) datasets and method, (4) results, and (5) conclusions, limitations and future study.

2. BACKGROUND

The Jubilee Line Extension (JLE) was a major London Underground project during the 90s that started operation in 2000; it played an essential role in connecting Central London with the Docklands and Canary Wharf, both of which are newly developed financial districts in East London. The JLE improved accessibility over an extensive area of East and South London where the river had long been a barrier. In the early proposal, the JLE project dedicated to support the urban regeneration and create new job opportunities by enhancing the mobility of two main stations, Waterloo and London Bridge, to Canary Wharf and North Greenwich with the extension to Stratford. The JLE impact study, by University Westminster in 2004, proved that the JLE had helped the economic growth in employment, population and house prices by increasing transport service and connection to West and East ends (Jones et al., 2004). This study, however, focused on the investigation of regional commercial and residential development, the local spatial impacts on neighbourhoods around the JLE stations have not been widely examined by urban studies.

In order to understand the impacts of the implementation of JLE around station neighbourhoods and provide a robust comparative framework, this research has set up two groups of case studies based on the distance between stations, as well as their population, economic and demographic status. The purpose of this was to examine station neighbourhoods with similar backgrounds and reduce the nature of geographical influences on the developments. The case study I used compared Bermondsey station and Canada Water station, both of which are new JLE stations located next to each other in the London Borough of Southwark. The functional difference between these two stations is that Canada Water is a transportation hub with London Overground access and multiple bus services. Bermondsey is only served by the Jubilee Line. Case study II, Canning Town station and West Ham station, are located in the London Borough of Newham and are one stop away from each other. Canning Town is a transport hub for both Jubilee Line and Dockland Light Railways (DLR) services with 10 additional bus services. On the other hand, West Ham was an existing station before the construction of the JLE and mainly served as an interchange transport hub to the Hammersmith & City Line, District Line, DLR and National Rail. These case studies provide a wider example of the neighbourhoods along the JLE which share similar demographic backgrounds but hold particular topology and spatial characters.

3. DATASETS AND METHODS

This research aims to examine if these JLE stations successfully embedded in the urban grids and how the built environment around the stations influence urban development in the fringe of London. Both qualitative and quantitative analysis for urban context around the station neighbourhoods has been applied to examine if the JLE influence the local development. The framework of this study contains three modules: (1) stations and neighbourhoods overview, (2) spatial analysis, (3) economic and social analysis.

3.1 STATIONS AND NEIGHBOURHOODS OVERVIEW

In the first module, the stations' usage data gathered from Transport of London (TfL) revealed the overall performance of each station and identified their characteristics as a station within the London Underground network. On-site observation presented the pedestrian movement pattern around the stations to identify the pattern of pedestrian flow and activity interact with space and the surrounding streets. This part of analysis would provide a general understanding of the environmental characteristics in the station neighbourhoods. Additionally, it also provides initial findings to identify the conditions of the stations and their connecting streets.

3.2 SPATIAL ANALYSIS

The second module of analysis starts from defining the station neighbourhood by the catchment distance, which is also known as metric step depth or point depth analysis in Depthmap. Instead of selecting the specific perimeter radius from the centre of stations, metric step depth follows the shortest path from the selected location (station) to all other segments (streets) within the street network, and the path length is calculated in meters (Turner, 2004). This approach is considered to be a feasible method for spatial analysis, since metric step depth is based on the distance between origin and destination through street network but not the linear distance between two points. It also enables this study to integrate spatial configurations and demographic data geographically through the urban fabric of street layout for the syntactic analysis. Previous studies suggested that 5 minutes to 15 minutes, which is equal to 400 meters to 1200 meters, is the average walking distance commuters would accommodate between the station and destination (O'Sullivan et al., 1996, Olszewski et al., 2005). Therefore, three scales of catchment distance are applied through the entire study (400m, 800m, and 1200m).

In order to evaluate the embeddedness of the stations with the surrounding urban structure, this study established a morphological urban block analysis including block size, block density, pedestrian path coverage, and infrastructure intrusion. GIS street datasets including urban path, transport infrastructure, and building plots (from Ordnance Survey/EDINA supplied service) were plotted in QGIS platform for both graphic and mathematical analysis.

London M25 segment map processed by space syntax analysis include 'normalised angular integration' (NAIN) and 'normalised angular choice' (NACH) were applied for a detail street network analysis (Hillier et al., 2012). These two methods of normalisations have immense advantages, making it easier to expose the inner structure of urban form, and making it possible to compare street configurations in different locations within a city (Al Sayed et al.,2014) Multiple metric radii for both NAIN and NACH measures were examined in this section for the understanding of both local and global accessibility of the street network. This analysis could provide both graphic and statistic evidence for identifying whether the stations embedded in the local and global network with high accessibility or segregation from the urban structure and street network.

3.3 ECONOMIC AND SOCIAL ANALYSIS

Previous research proposed that the diversity of land use distribution is reliant on the movement patterns in the urban realm (Geddes and Vaughan, 2014). It suggested that the active land use along the pedestrian path is associated with the walkability and connectivity which would encourage local economic activities. Therefore, this study looked into the distribution of land uses around station neighbourhoods (i.e. residence, retail, service, education, industry, leisure and transportation) in order to verify whether the spatial configuration affects the economic development. The land use data, which is in Point-of-interest format, is derived from Ordnance Survey AdressBase® Plus and processing into five groups including residential, public (education, service, government, hospital, office), retail, industrial, and mix (contain more than one function in the single building plot) in QGIS platform.

The social statistical analysis was set up to test the hypotheses that urban morphology and spatial conditions influence social status and regeneration through time. This study obtained three statistics datasets: The UK House Price Paid data between 1999 and 2016 from HM Land Registry, Residence Population data between 2001 and 2012 from The Office for National Statistics, and The Indices of Multiple Deprivation (IMD) from Department for Communities and Local Government (DCLG). The IMD is constructed by combining seven domains: income, employment, health, education, barriers to housing and services, crime, and living environment. In order to transform these data sets to be comparable with the catchment segment model around stations, all the data were plotted in QGIS and weighted by the street segment for each area in different scales. The syntactic analysis which integrates socioeconomic datasets with spatial configurations allowed this study to implement an in-depth evaluation and comparison between selected station neighbourhoods.

4. RESULTS

4.1 Stations and Neighbourhoods Overview

In case study I, Bermondsey serves as a JLE only station but Canada Water is an interchange station for both Underground and Overground services plus eight additional bus routes. Bermondsey station located in a residential area surrounded by many retailers and restaurants. Canada Water station sits next to a high-rise high density residential area, where is close to a suburban shopping centre.

In case study II, Canning Town station is an intermodal metro and bus station with Underground, DLR and bus services. The area was once an industrial zone, but it is now surrounded by high-rise residential buildings with some mixed-use development construction sites nearby. On the other hand, West Ham is an intermodal station, served by multiple Underground Lines, DLR and National Rail. It was rebuilt and significantly expanded in 1999 for the JLE project. The west side of the station is still an industrial area, and the east side is a low-density residential area.

4.1.1 Station Usage

In case study I, the daily usage in 2015 of Bermondsey and Canada Water (Chart 1) showed the entry and exits are quite similar in these two stations, however, the major difference is the interchange number which was about 75% of total usage in Canada Water.

In case study II, the usage in Canning Town and West Ham indicate that both stations mainly serve as transport hubs for interchange, but the percentage of interchange in West Ham was close to 90% which indicates the number of passengers from its neighbourhood is extremely low. Moreover, 88% of interchange was connecting to or from Jubilee Line in West Ham, only 12% of interchange was related to other line services, which suggests that the JLE service dramatically increased the usage for West Ham station, however, passengers only made interchanges inside the station without visiting the neighbourhood.

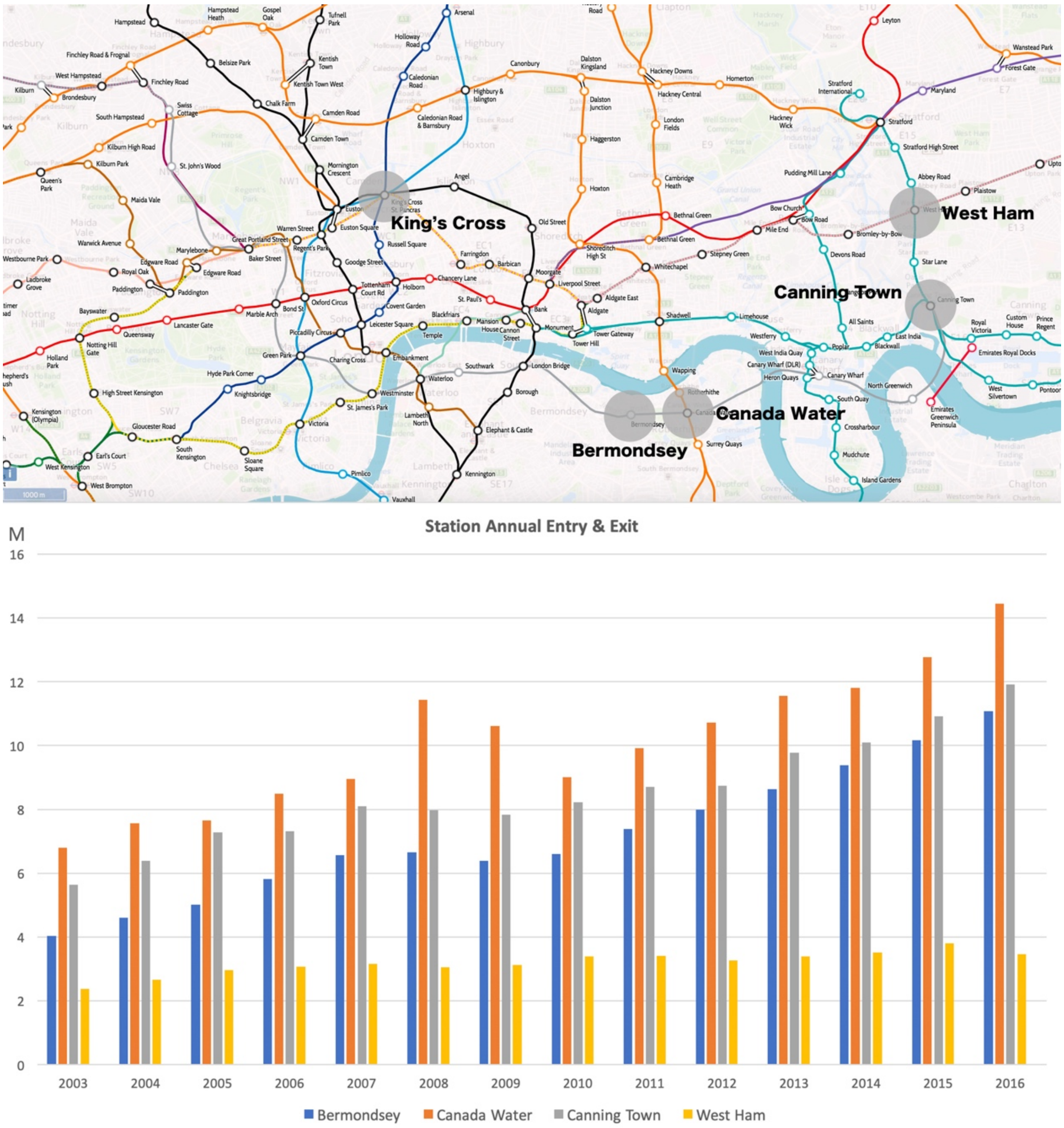

Figure 01 Station and Underground network overview, Station annual entry & exit

	Bermondsey		Canada Water		Canning Town		West Ham	
Entry	16242	52%	17822	12%	17041	17%	5931	6%
Exit	15132	48%	19969	13%	16542	17%	5779	6%
Interchange	0	0	115226	75%	65117	66%	83339	88%
Total	31374	100%	153017	100%	98700	100%	95049	100%

Chart 1. 2015 Bermondsey and Canada Water Station Daily Usage

4.1.2 Pedestrian Movement

In case study I, the pedestrian movement pattern and street snapshot photos (Figure 02) indicate that pedestrian movement was high along the main street adjacent to Bermondsey station, but movement dropped down immediately on the secondary streets which lead to the residential area. It appeared that most of the pedestrians moved linearly along the main street, especially on the side with more retailers. In Canada Water neighbourhood, the observation showed that the Deal Porter square in front of the station building and the evenly distributed residential areas, as well as the shopping centre on the south-east, attract pedestrians moving in various directions depending on the purpose of their trips. It also indicated that there are numbers of people standing next to the station waiting for the bus.

Although the diversity of the land use could support multi-functional local activities around Canada Water station, the pedestrian movement was lower than Bermondsey station.

In case study II, the snapshot observation (Figure 02) around Canning Town station showed that the pedestrians are walking mainly in between the local high street and station. Even though there are some environmental disadvantages to this station, including the intruding of wide vehicular lanes, Underground transport infrastructure, and the river passing through the west, Canning Town station is still well connected to the local centre by the surrounding streets. On the other hand, the pedestrian movement was much lower in West Ham which is only distributed on one side of the street where people are reluctant to cross the street. Moreover, the environment is not made for pedestrians with massive railway infrastructure cutting through the connecting street to the north of the residential area. Although previous usage analysis indicated that West Ham has a high volume of interchange passengers, the observation showed nearly no activity happening around the station with only two shops in front of it.

The results of the observation form case I and II implied that the pedestrian somehow follow the rules of ‘natural movement’ around the stations where most of the flow occurs on the main street and appears to diminish on the secondary routes (Hillier et al., 1993).

Figure 02 Snapshot—pedestrian activity around the station.

4.2 Spatial Analysis

4.2.1 Metric Step Depth

In Figure 03, the street network in orange represents the 1200m catchment area of Bermondsey and Canada Water. It can be seen that the structure of the street segments is evenly distributed in both station neighbourhoods. Around 400m catchment of Canada Water, the graphic shows that the coverage of streets is low due to the huge urban blocks near the station. The statistics (Chart 2) shows that Bermondsey has a higher street coverage than Canada Water in all scales of catchment. From this one can conclude that the street network in Bermondsey is structured in a better condition than Canada Water because of the higher density and total lengths of street segments.

In case study II, the catchment graphics (Figure 03) show that there are huge urban blocks near both Canning Town and West Ham stations which could affect the connectivity of street networks in proximity. Within the 800m catchment area, however, the graphics and the statistic results (Chart 2) indicate that Canning Town has a longer total length of street segments with a lower average street segment length (Canning Town 53m, West Ham 61m). These results suggest that Canning Town has a higher street density within 10 minutes walking distance from the station, whereas West Ham has poor street coverage in the same catchment. In other words, it indicates that the structure of street network within 800m catchment in Canning Town is in better condition to generate local pedestrian movement. Moreover, this could factor in support of the local economic development.

	Bermondsey		Canada Water		Canning Town		West Ham	
	Sum	Mean	Sum	Mean	Sum	Mean	Sum	Mean
400m	4940	70.56	2546	68.81	4657	53.52	4128	58.14
800m	22192	44.03	17195	47.63	18962	53.41	12880	61.62
1200m	50759	46.22	38612	48.02	42128	51.12	34704	61.51

Chart 2. Street Coverage in Meters Case Study I & II

4.2.2 Urban Form and Structure Effect

Figure 03 shows the urban context of case study I and II. In case study I, the density of streets and pedestrian paths is higher in Bermondsey than Canada Water, especially within 400m catchment. Although there is massive railway infrastructure penetrating the south of the Bermondsey neighbourhood, the continuity of the street network is not affected. On the other hand, there are large urban blocks around Canada Water station which could possibly decrease the connectivity of the street network. In the statistics comparison (Chart 4), it also revealed that the mean and median values of urban block size in Bermondsey are lower than Canada Water, especially in 400m catchment. Moreover, the urban block size data showed the upper 50% in Bermondsey 400m catchment area is much smaller than Canada Water, which provides more evidence to the comparison of urban block coverage. Although the building density (Chart 3) within 400m catchment for both stations are about the same, the building density within 800m catchment is much higher in Bermondsey than in Canada Water. This result suggests that between 5 to 10 minutes walking distance, the Bermondsey neighbourhood might be able to sustain commercial and residential uses with higher building density. With this evidence, it can be concluded that the Bermondsey neighbourhood has better spatial conditions than Canada Water, it also has a higher density of buildings and streets which provide better network connections around station.

In case study II, both Canning Town and West Ham stations are surrounded by massive urban blocks and divided by railways and streets (Figure 03). However, Canning Town is located close to a local high street with a higher density of street network, whereas West Ham is further away from local high streets with a lower density of street network, especially within 400m catchment. The statistic analysis (Chart 5) showed that both areas have higher median and mean values of urban block size within 400m catchment than 800m catchment, this might affect the connectivity of the streets around station, but West Ham neighbourhood has bigger urban blocks which make it difficult to connect the local to the global street network. The result of building density (Chart 3) also supports the hypothesis from the previous catchment analysis that Canning Town has much higher street density than West Ham. Combining the graphic illustration and statistics results, it can be seen that, morphologically, Canning Town has better spatial conditions in the connectivity of street and building density than West Ham.

	Bermondsey	Canada Water	Canning Town	West Ham
400m	31.2%	32.5%	45.9%	17.9%
800m	42.3%	29.2%	27.1%	19.0%
1200m	34.0%	21.4%	30.0%	21.0%

Chart 3. Building Density in Percentage Case Study I & II

	Bermondsey 400m	Canada Water 400m	Bermondsey 800m	Canada Water 800m	Bermondsey 1200m	Canada Water 1200m
N	35	22	82	69	87	61
Mean	8320.31	15742.05	5843.13	6321.78	12540.06	16932.82
Median	5315.00	8722.50	4149.00	4547.00	8227.00	9857.00
Std. Deviation	7635.33	18565.79	6118.19	5244.06	16434.79	25195.43
Minimum	865	1636	222	1068	392	1298
Maximum	33061	70948	45336	25959	134191	167329
Sum	291211	346105	479137	436203	1090985	1032902

Chart 4. Urban Block Coverage Case Study I

	Canning Town 400m	West Ham 400m	Canning Town 800m	West Ham 800m	Canning Town 1200m	West Ham 1200m
N	16	19	55	40	94	78
Mean	8804.38	15079.00	8236.85	17032.00	13145.83	22851.95
Median	7392.00	13031.00	5190.00	7808.50	9045.50	10788.50
Std. Deviation	4697.59	13583.96	9414.25	25638.54	13912.54	43117.44
Minimum	1214	3725	916	1661	1324	3140
Maximum	19158	59609	54733	122354	92598	288733
Sum	140870	286501	453027	681280	1235708	1782452

Chart 5. Urban Block Coverage Case Study II

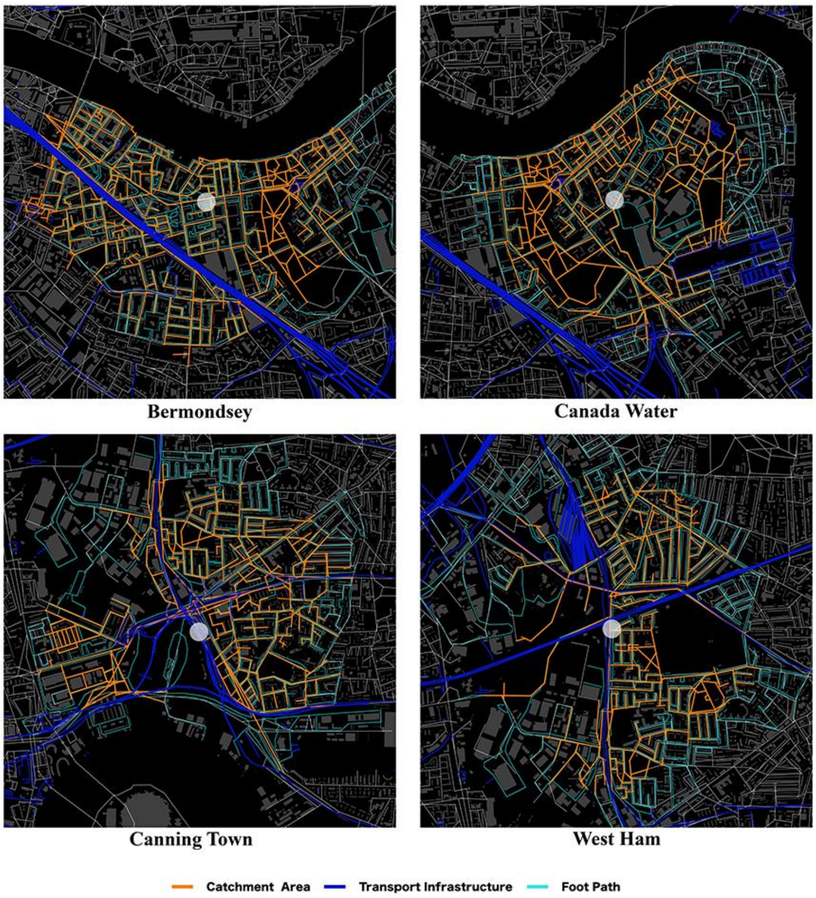

Figure 03 Station catchment area, foot path, and transport infrastructure.

In respect of movement economies (Hillier, 1996), the above-mentioned spatial conditions in terms of urban form and density in these two cases, are part of the factors for the multiplier effect which could help local economy, but simply not enough to determine the overall conditions. The following spatial network analysis of connectivity and accessibility could better reveal the insight of the built environment in the station neighbourhoods in the following section.

4.2.3 Network Accessibility

In case study I, the integration analysis (NAIN) in radius N and 2000m (Figure 04) show that both Bermondsey and Canada Water stations are at the positions with high connectivity to the global street network. The integration analysis in the smaller radius of 1200m and 800m indicate that Bermondsey station is located on the highest integrated local high street, but Canada Water is further away. In addition, there is high global and local to-movement around Bermondsey station while Canada Water station has low local to-movement nearby. The statistics (Chart 6.1) also support the hypothesis of the graphic interpretation by showing that Bermondsey has better connectivity within 400m catchment especially in Integration 1200m radius.

The choice analysis (NACH) presented similar results to the integration analysis (NAIN), and the street networks within these two station neighbourhoods are structured well with both global and local through-movement (Figure 04). It also showed that the choice analysis in radius 1200m captures the urban layout more clearly than other radii with the main local streets in high choice value. It suggests that the Jamaica Road (A200) in front of Bermondsey station, which also close to Canada Water station, has a high value of pedestrian movement flows when the travel distance is about 1200m. Furthermore, it shows that the movement drops down in the secondary streets connecting to Jamaica Road where the residential buildings, as the background network, located. The statistics (Chart 6.1) also verify that both areas have high volumes of through-movement within 400m catchment, but Bermondsey performed slightly better in every testing radii than Canada Water. In summary, both areas benefit from their geographic locations, which are close to the Central London with a high volume of global movement around the station, but Bermondsey neighbourhood has better spatial conditions to support local movement.

Case study II shows significant difference between Canning Town and West Ham station neighbourhoods in terms of integration analysis with radius N. Figure 04 portrays Canning Town surrounded by the streets with extremely high integration value which could potentially become a local centre, whereas West Ham is located away from the global high integrated streets and surrounded by lower integrated ones. From the statistics of integration analysis, the result also revealed that Canning Town has a much higher value than West Ham in all testing radii within 400m catchment (Chart 6.2). The images of choice analysis (NACH) from radius N to radius 800m (Figure 04) indicate that both stations located at the high global and local through-movement segments. Furthermore, the choice value boxplot in 400m catchment (Chart 6.3) demonstrated that the composition of street networks in Canning Town are structured better with a low standard deviation, while the bottom 50% of segment choice value in West Ham are far lower than the median. This suggests that the structure of street networks around West Ham station is in a bad condition even though it is located on the street with higher global and local through-movement. The volume of pedestrian movement decreases much faster in the connecting streets which leads to the surrounding residential area with no intermediate ones could support local economic activity.

Vaughan and Griffiths (2013) indicated that the small city centres in London's suburbs usually have the most spatially accessible streets to support retails and other non-residential land use because the built environment of London's suburbs is well adapted to sustain a wide variety of activates. This phenomenon could be found in the neighbourhood of Bermondsey and Canning Town stations with the ability to develop local economies by both global and local network accessibility. Whereas in Canada Water and West Ham, the public transport network increase the global connection to the broader network but the inherent street network surrounded in the station neighbourhood has less support to the local community and the rest of the city.

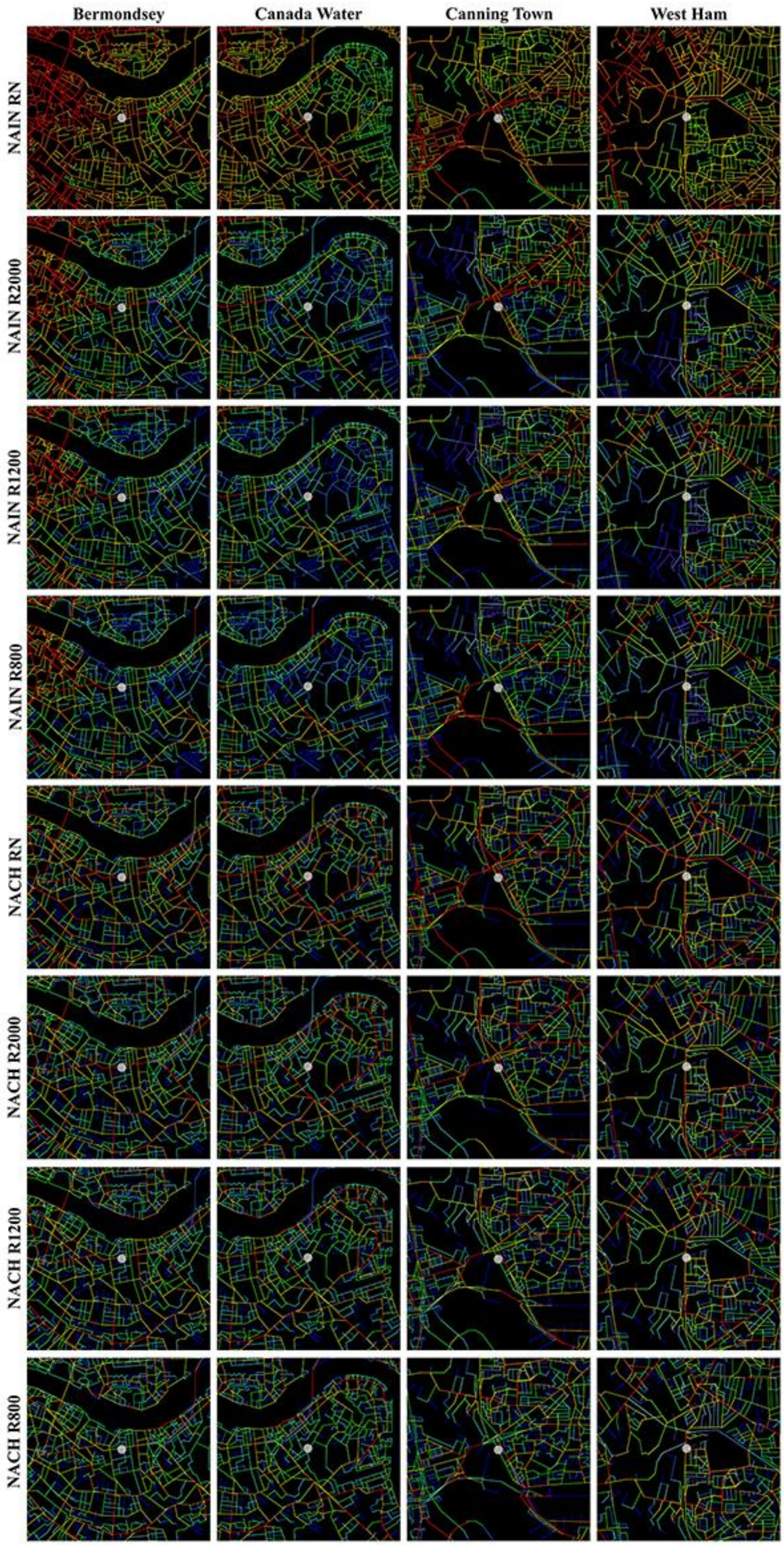

Figure 04 Normalise Integration & Choice Analysis in Case Study I & II

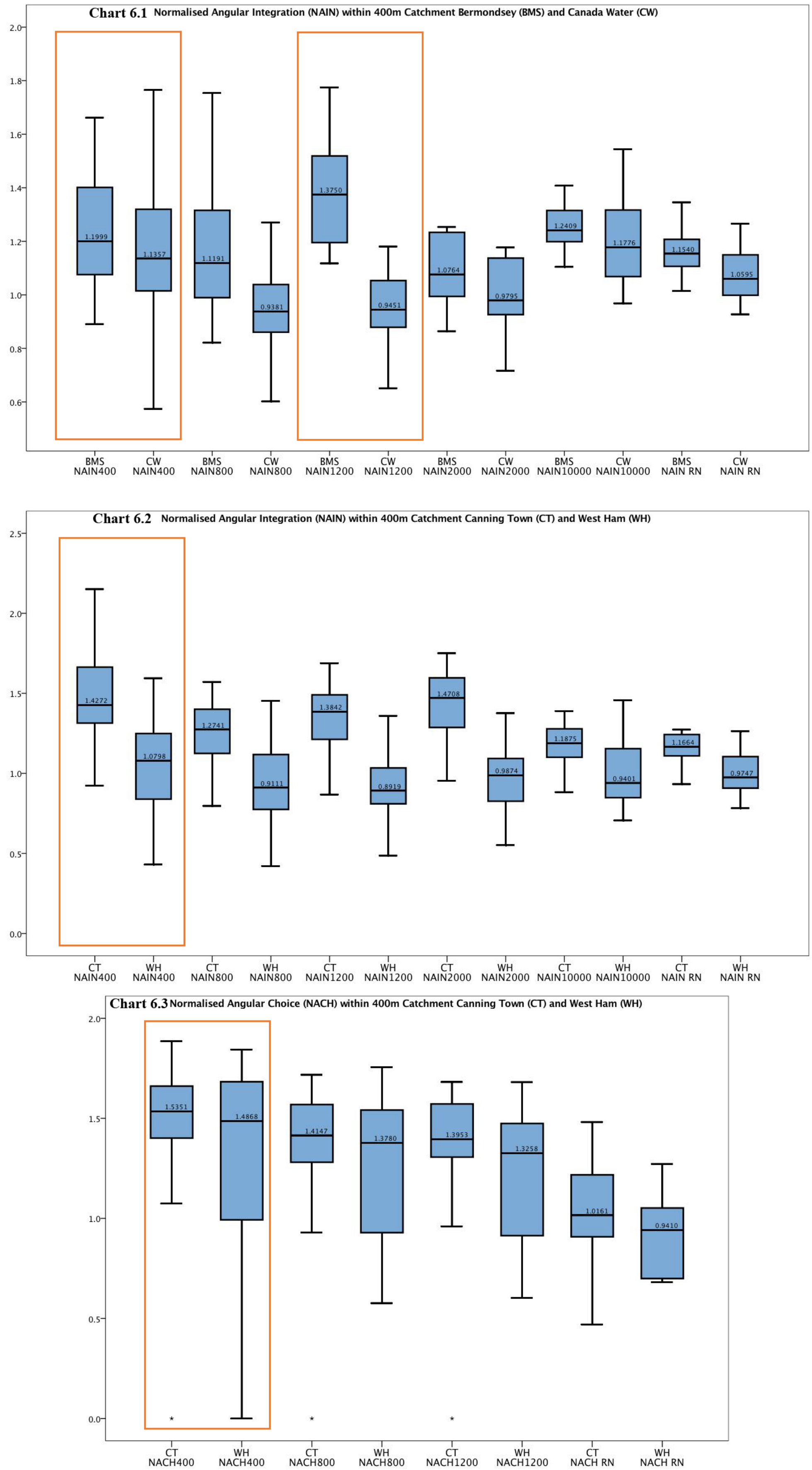

Figure 05 Boxplot for Integration and Choice Analysis in 400m Catchment Case I & II.

4.3 Economic and Social Impact of the Stations

4.3.1 Land Use Distribution

In case study I (Figure 6.1, 6.2), the graphics illustrate that both Bermondsey and Canada Water neighbourhoods are mainly occupied by residential buildings. Most of the commercial and retail buildings in Bermondsey are located close to the local high streets which attract a high volume of local and global movement. Previous research suggests that the diversity of active land use could potentially enhance pedestrian movement and support long-term economic development (Geddes and Vaughan, 2014). Therefore, the condition of land use distribution and street network in Bermondsey could potentially generate multi-purpose trips around the station. In Canada Water neighbourhoods, comparatively, the distribution of non-residential buildings and huge urban blocks, combined with the low street connectivity, this might divide the area and create spatial segregation which could hinder pedestrian movement and economic activities.

In case study II (Figure 6.3, 6.4), the graphics show that transport infrastructure dominates the land use distribution. Most of the industrial and non-residential land uses are spread out on the west side of railway tracks with huge urban blocks, but residential land uses are distributed on the east side with smaller urban blocks and high density of streets. The environment in Canning Town appears to be more attractive for pedestrians, especially on the high street leads to the station. Whereas the land use distribution appears to be segregated in West Ham, only a small portion of residential buildings located around the station, most of the non-residential buildings, especially the retailers, are scattered away from the station. The land use distribution reveals that there are fundamental disadvantages of urban structure and spatial layout in West Ham neighbourhood.

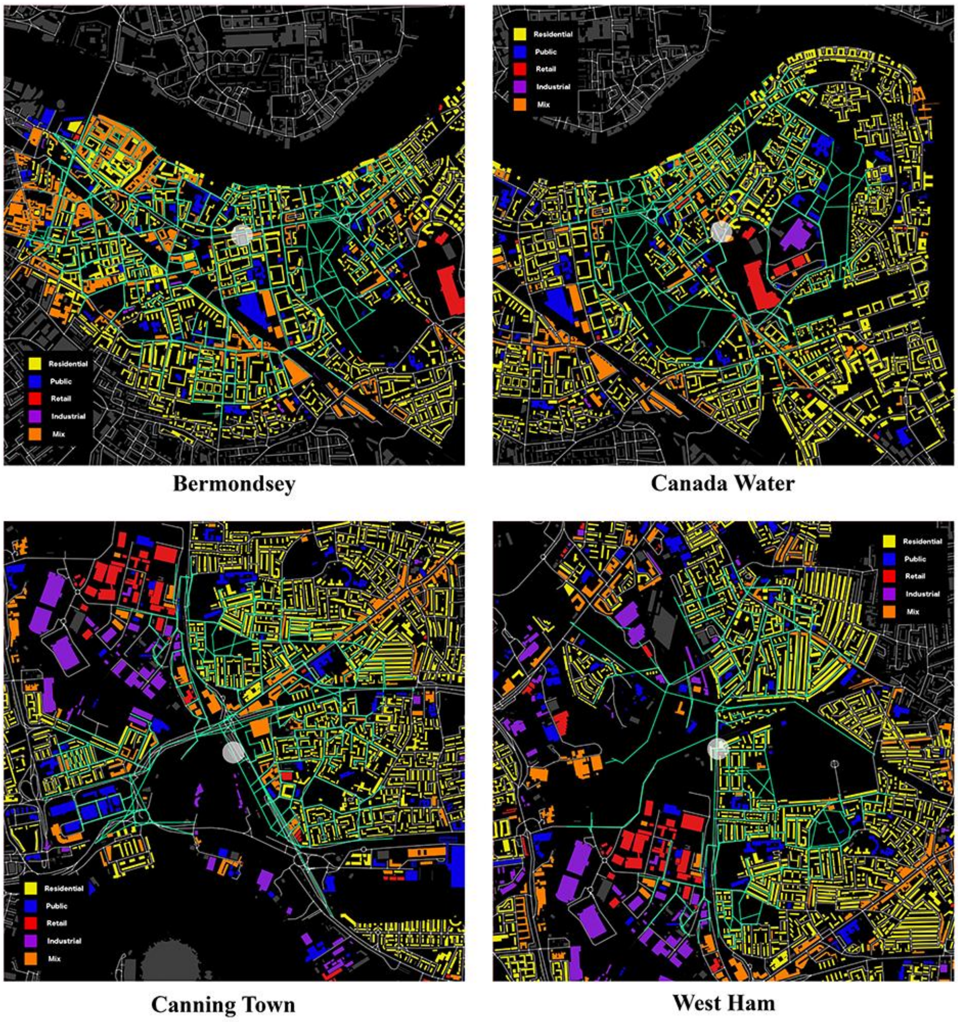

Figure 06 Land Use Map in Case Study I & II.

4.3.2 Shop Distribution in Station Catchment

In this section, the spatial configuration of space syntax measured from 4.2.3 was applied to the analysis of the retail distribution variables for the correlation analysis between network accessibility and retail activity. The average value of 'integration' and 'choice' within the multiple scales of catchment, which represented the spatial variables, have been tested with these retail variables: total numbers of shop, average shop distance, and shop density based on the retail point data. The Pearson correlation has been applied for the statistical analysis, and to identify if the variables are statistically significant.

Analysis	Properties	Count	Distance(M)	Density(Per100m)
NACH R400	Correlation	0.525	-0.215	0.545
	Sig. (2-tailed)	0.285	0.682	0.263
NACH R800	Correlation	0.575	-0.251	0.579
	Sig. (2-tailed)	0.232	0.632	0.228
NACH R1200	Correlation	0.13	0.317	0.125
	Sig. (2-tailed)	0.806	0.541	0.813
NACH R2000	Correlation	0.661	-0.466	0.68
	Sig. (2-tailed)	0.153	0.352	0.137
NACH R10000	Correlation	0.8	-0.647	0.81
	Sig. (2-tailed)	0.056	0.142	0.051
NACH RN	Correlation	0.855*	-0.647	0.857*
	Sig. (2-tailed)	0.03	0.165	0.029
NAIN R400	Correlation	0.647	-0.26	0.648
	Sig. (2-tailed)	0.165	0.619	0.164
NAIN R800	Correlation	0.566	-0.111	0.531
	Sig. (2-tailed)	0.241	0.834	0.279
NAIN R1200	Correlation	0.667	-0.365	0.639
	Sig. (2-tailed)	0.148	0.476	0.172
NAIN R2000	Correlation	0.837*	-0.555	0.811
	Sig. (2-tailed)	0.038	0.253	0.05
NAIN R10000	Correlation	0.426	-0.777	0.431
	Sig. (2-tailed)	0.399	0.069	0.393
NAIN RN	Correlation	0.693	-0.812*	0.691
	Sig. (2-tailed)	0.127	0.05	0.128

Chart 7. Pearson Correlation Between Shop Distribution and Space Syntax Analysis 400 Catchment of Stations Case I & II

The result of correlation analysis within 400m catchment (Chart 7) showed that Choice in radius N, and Integration in radius 2000m correlate better with shop numbers and density. Integration radius N correlate better with shop distance. This result indicated that the global movements influence the local economic activities in the station neighbourhoods within 400m. The correlation in 800m catchment (Chart 8) show that Choice in every radius correlates well with shop count and distance. Integration value in radii smaller than 2000m have good correlation with shop density. The Integration in radius 800m has the best correlation with distance and density. However, there is no significant correlation found within 1200m catchment between spatial configuration and shop distribution.

To summarise, when the street with higher global Choice in radius N and higher local Integration in radius 800m, it has the highest potential to support the economic activity around the station catchment. The spatial accessibility and network connectivity not only influence the streets adjacent to the station but the influence becomes stronger in the areas between 400m to 800m. However, the effect diminishes after 800m catchment distance. It also indicated that the network structure of centrality and connectivity in the station catchment is likely to support multi-purpose trips for passengers on their route between station and destination. However, to provide a better correlation analysis, data from other London Underground stations is needed to enlarge the database.

Analysis	Properties	Count	Distance(M)	Density(Per100m)
NACH R400	Correlation	0.869*	-0.704	0.368
	Sig. (2-tailed)	0.024	0.118	0.473
NACH R800	Correlation	0.913*	-0.816*	0.573
	Sig. (2-tailed)	0.232	0.632	0.228
NACH R1200	Correlation	0.871*	-0.839*	0.599
	Sig. (2-tailed)	0.024	0.037	0.209
NACH R2000	Correlation	0.907*	-0.872*	0.643
	Sig. (2-tailed)	0.012	0.023	0.168
NACH R10000	Correlation	0.894*	-0.839*	0.624
	Sig. (2-tailed)	0.016	0.037	0.186
NACH RN	Correlation	0.842*	-0.809	0.566
	Sig. (2-tailed)	0.035	0.051	0.241
NAIN R400	Correlation	0.76	-0.725	0.804
	Sig. (2-tailed)	0.08	0.103	0.054
NAIN R800	Correlation	0.685	-0.814*	0.919**
	Sig. (2-tailed)	0.133	0.048	0.01
NAIN R1200	Correlation	0.498	-0.74	0.832*
	Sig. (2-tailed)	0.315	0.093	0.04
NAIN R2000	Correlation	0.647	-0.715	0.812*
	Sig. (2-tailed)	0.165	0.11	0.05
NAIN R10000	Correlation	0.07	-0.434	0.275
	Sig. (2-tailed)	0.896	0.39	0.598
NAIN RN	Correlation	0.35	-0.655	0.676
	Sig. (2-tailed)	0.496	0.158	0.14

Chart 8. Pearson Correlation Between Shop Distribution and Space Syntax Analysis 800 Catchment of Stations Case I & II

4.3.3 House Prices

In order to investigate the range of the station impact on house prices and transactions, the house prices data set was integrated with street network for comparison in the case studies. By comparing the average annual house prices between 400m, 800m and 1200m catchment from station, it revealed that the influence of stations on house prices is limited to the small catchment area. House prices would be dominated by regional housing market beyond 800m catchment. Interestingly, the curves in annual price charts (Chart in Figure 07) illustrated a decrease of house prices from 2007 to 2009, which is the period when the global financial crisis hit the UK housing market. Until recent years, the housing market starts to recover from the financial crisis. The curves in these charts provide the evidence that the price was fluctuating after 2007 and began to climb up between 2012 and 2013.

The house price comparison between Bermondsey and Canada Water 400m catchment (Chart in Figure 07) shows that the price jumped up from 1999 to 2000 in Bermondsey area, which is also the year the JLE began to operate. The price starts to increase two years before the beginning of JLE service at Canada Water station. Both areas suffered from the financial crisis but reacted differently. Bermondsey rebounded from the crisis quickly and the price kept increasing gradually while the price in Canada Water fluctuates constantly.

The average house prices were about the same at the beginning of 1995 in Canning Town and West Ham, however, after 2001 the price increased faster in Canning Town than West Ham. Furthermore, the curves imply that Canning Town area rebounded from the financial crisis with a promising increasing trend while the prices remained fluctuating in West Ham neighbourhood until 2013.

4.3.4 Population Density

In case study I (Chart 7.1), the population density was constantly higher in Bermondsey than in Canada Water, the results might be associated with the high residential building density within Bermondsey 400m catchment. The curves in chart 7.1 indicate that population density gradually increased in Bermondsey before 2009 whereas there was little to no change in Canada Water during the same period. After 2009, the year the financial crisis ended, the population density began to climb in both areas and remained at the same increasing rate till 2015.

The chart 7.2 shows the results for case study II. During the financial crisis from 2006 until 2009, the population density dropped down in Canning Town while the density increased in West Ham. After the financial crisis, the density in Canning Town started to increase, but it stopped growing in the West Ham neighbourhood. Comparing with the house prices catchment analysis in the previous section, it suggested that house prices and rental prices might be the key to this phenomenon. During the financial crisis, people moved from more expensive areas to less expensive areas. However, further research on the correlation between population and house prices is required to verify this hypothesis.

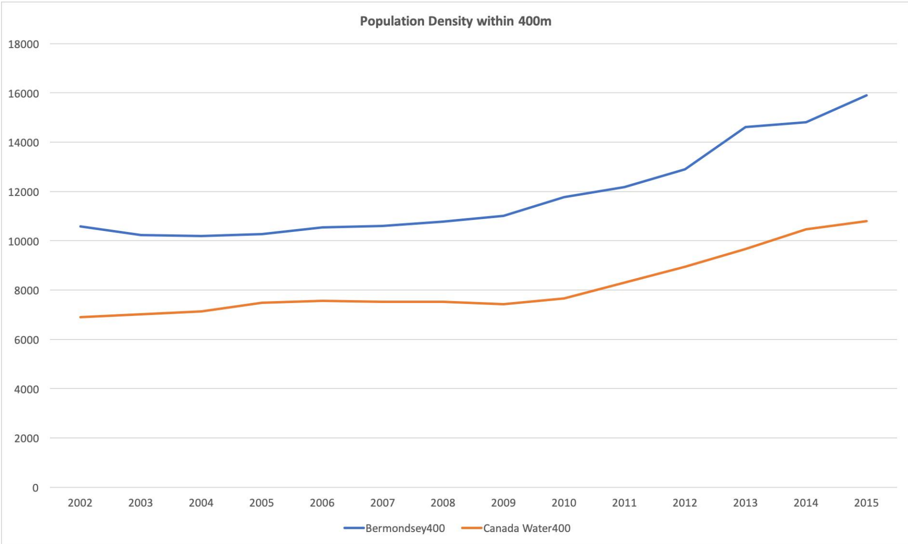

Chart 7.1 Population Density Case Study I

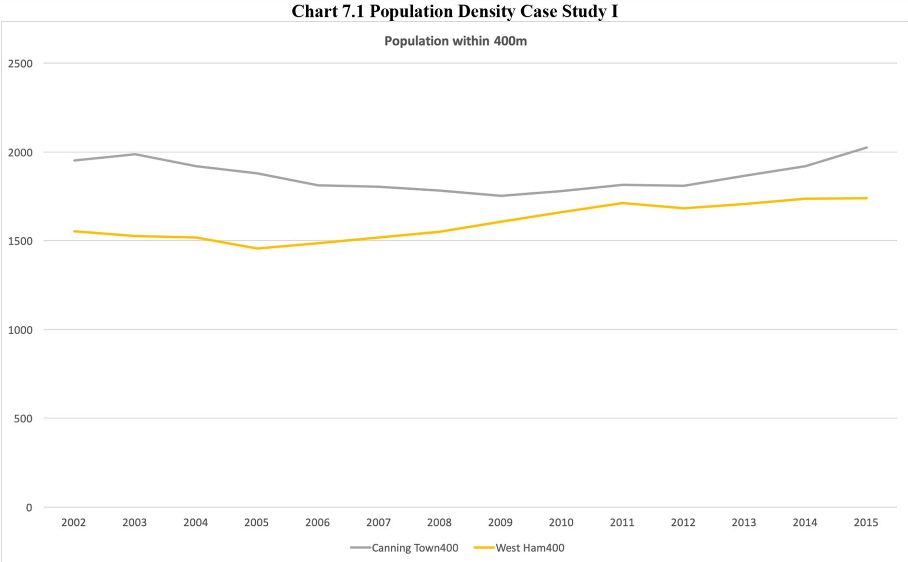

Chart 7.2 Population Density Case Study II

Figure 07 House Price Map 2011-2016 quantile 10 classes and Price Chart 1995-2016 for Case Study I & II.

4.3.5 IMD: Income and Employment

Geographically, Bermondsey and Canada Water are not far away from Central London and both areas are less deprived than other case study areas. Chart 8.1 shows that the declining rate of deprivation from 2004 to 2010. Both Bermondsey and Canada Water areas performed better than the average London score, which had not changed much since 2004. After 2010, the decline rate of deprivation slowed down in Bermondsey but it climbed up again in Canada Water. It is more clear that the income status of Bermondsey has constantly increased since 2004, but more fluctuated in Canada Water even though it is close to the average score of London (Chart 8.2). The employment curves for both areas show similar pattern through 2004 to 2015 (Chart 8.3). Canada Water performed better than London and Bermondsey. This might be the effect of the global transport network that Canada Water station providing better connections to jobs in the city centre. Further investigation of the public transport network is needed to verify this phenomenon. From the IMD and income score, this analysis suggests that the social status within Bermondsey catchment had been constantly improving faster than Canada Water catchment area.

In case study II, both Canning Town and West Ham are located in areas which are geographically further from the city centre and demographically more deprived than other London boroughs. The IMD and the income score indicated that the social status in Canning Town catchment had been improved continuously since 2004 whereas West Ham catchment did not improve until 2010 in West Ham (Chart 8.2). The employment improvement rates perform better in Canning Town than West Ham even though the score is better in West Ham (Chart 8.3). Similar to the case study I, it might be the global transport network effect for the employment status since West Ham has more services of the London Underground, National Rail and DLR than Canning Town.

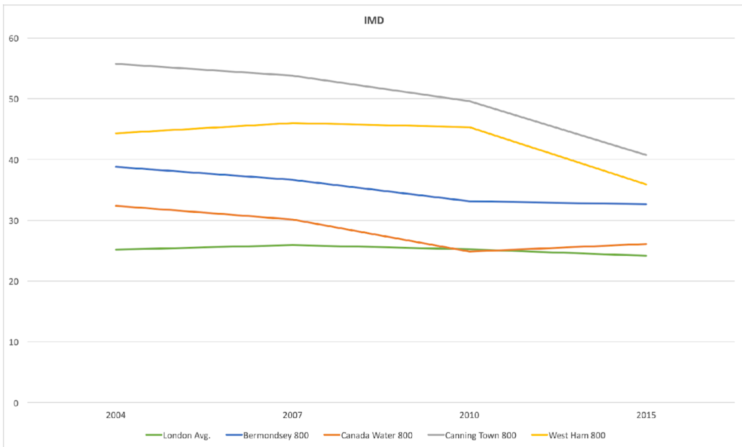

Chart 8.1 IMD Catchment 800m Case Study I & II

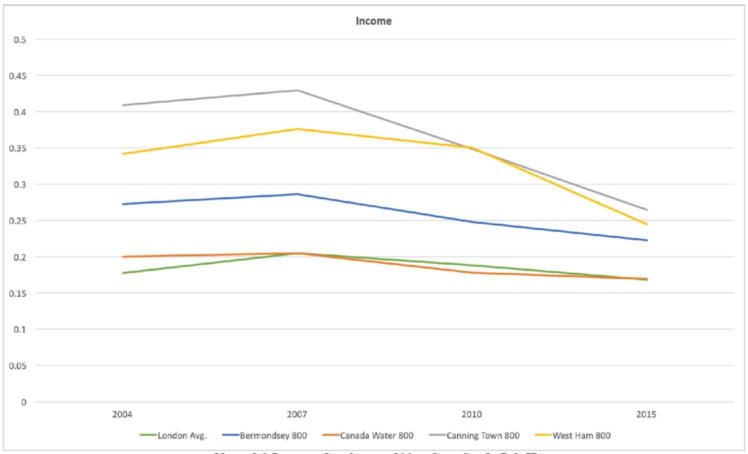

Chart 8.2 Income Catchment 800m Case Study I & II

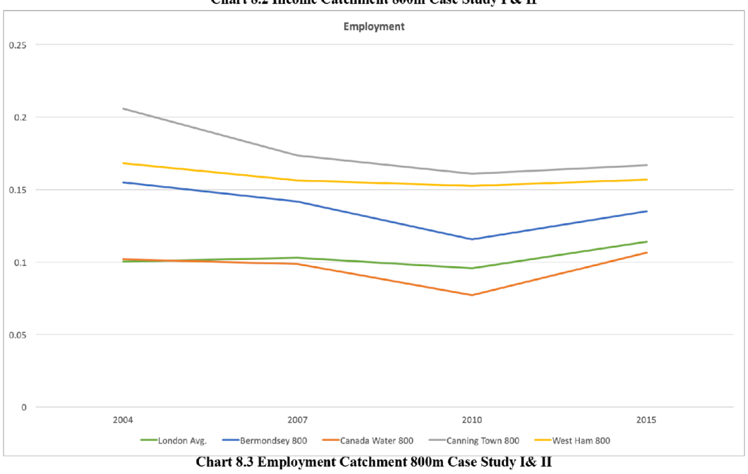

Chart 8.3 Employment Catchment 800m Case Study I& II

4.4 Summary

Bermondsey VS Canada Water

In case study I, although both Bermondsey and Canada Water were geographically close to the city centre, the station usage indicate that Canada Water might be a more important node within the transport network as it provides multiple services for both north-south and east-west directions. The pedestrian movement from the observation, however, pointed in the opposite direction that Bermondsey is busier near the station than Canada Water. The spatial analysis identified that although both areas have some morphological disadvantages, Bermondsey has better network accessibility globally and locally in the station catchment which could support the urban activities compared to Canada Water. The economic and social performance in house prices, population, and IMD further revealed that Bermondsey has better socio-economic growth since the beginning of the JLE service.

Canning Town VS West Ham

The analysis in case study II provided a more convincing outcome. The usage in Canning Town increased every year after the JLE but the usage in West Ham has not changed noticeably through 2003 to 2016. With more connecting services for Underground, National Rail and DLR, West Ham station was meant to attract more travellers but this has not happened. Spatial analysis, especially the space syntax integration and choice analysis, uncovered that the network accessibility in the West Ham neighbourhood is low in both global and local scales. The socio-economic analysis also reflected that the inherent urban structure might be the reason to impede the local development in West Ham even with a well-connected station which provides multiple services to the city.

The spatial analysis together with the socioeconomic datasets from these two case studies demonstrated that the stations influence the local economies and development. This phenomenon might directly relate to the new transport system, however, more importantly, the configuration of the spatial entity play a vital role to amplify this result (Karimi, 2012). Previous space syntax studies have found that the inherent urban structure of suburban city centres could be essential to support the global and local movement for the long-term economic and social sustainability (Griffiths, 2009; Vaughan et al., 2010). The neighbourhood of the case studies' stations similarly revealed the spatial conditions determine the local development. Therefore, it is necessary to consider the further spatial effect of the built environment when designing and planning the new public transport system.

5. CONCLUSIONS, LIMITATIONS AND FUTURE STUDY

This research established an analytical methodology based on space syntax measures to examine the morphological and topological spatial characteristics of the four station neighbourhoods along the Jubilee Line Extension. The spatial analysis provided a syntactic approach to understanding the urban fabric in the neighbourhood and the socio-economic performance, revealing the spatial influence of public transport system on urban activities. The outcome proved that space syntax as a set of theories and methodology could bring transport and urban study together and identify the spatial impact on the station neighbourhoods after the implementation of a new public transport system.

The case studies indicated that the station which sits in a place with high network accessibility would potentially be a successful implementation to optimise the development and urban activities in the neighbourhoods. On the other hand, the station with the spatial disadvantage might impede the local development even the station has high usage and connects well to the global transport network. Several spatial conditions which could determine the growth of socio-economic and urban activities in the station neighbourhoods have been verified in this study:

- The density of street network
- Connectivity and accessibility to both local and global network
- The size of urban blocks
- Density of buildings
- The intrusion of transport infrastructure

With the results from the morphological study with the socio-economic data, this study has shown that the spatial conditions and location of the station play a critical role in optimising the urban development and regeneration. It also reflects that urban form and spatial accessibility together with land use diversity could provide a multiplier effect for the regeneration of local economies (Hillier, 1996), especially around the stations. Additionally, this supports the findings from previous research that the spatial impact around the station can be considered as a configurational effect of the urban structure (Chiaradia, 2005). There is a need to adopt analytical approach through the design of the stations because the permanent infrastructure would bring long-term irreversible influence to its immediate surroundings, and eventually, manifested by the spatial entity (Karimi, 2012; Bolton, 2015).

There are limitations to the socio-economic analysis in this study, as a boundary census data in population and IMD scores were used instead of a dataset based on address points. The analysis showed that station may play an important part in the housing market, yet a further study in economy by applying the hedonic model to demonstrate this influence is needed to come to conclusive results.

In order to provide a holistic understanding of the influence of rail-based public transport systems, it is necessary to investigate more stations and their local impact. In terms of global spatial impact, it is imperative to consider the travel time between the origin and destination nodes, as well as the topological effect of the links. As space syntax methodology is focused mainly on the configurational effect of urban structure and street networks, the space-time effect of the transport network must be explored further for the comprehensive study of network accessibility. Therefore, an integrated multimodal urban network model which combines time-based data and street segments model should be built and applied for the future urban and transport study on the public transport development.

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