How the Railway Network and TOD Projects Impact the Spatial Accessibility on Different Scales

by

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Abstract

In the whole world, TOD has been seen as a comprehensive strategy to address or improve ' urban diseases ' such as traffic congestion, single land use type, unreasonable resource allocation and lack of walking space(Lyu, Bertolini, and Pfeffer 2016). Railway in London is one of the oldest and most complex railway networks in the world. In modern society, the TOD strategy has gradually become an important driving force for the internal development of London and the revival of declining areas. However, most studies about TOD based on spatial syntax theory are still in its infancy, and there is still no widely acknowledged evaluation system and standard model.

In order to better analyze the impact of the public transportation system on urban configuration attributes and the role of TOD projects in shaping the local spatial form and guiding the distribution of functions, a new multimodal network which adds a railway layer to replace the traditional street-based network has been introduced in this study to reflect the influence of railways on spatial accessibility and global network structure by the comparison within two models.

The results reveal that the rail network has an important optimization effect on urban development in at least two dimensions. Firstly, it can effectively promote the spatial accessibility of the area that occupies the outside in the geometric structure of the city especially in the context of global analysis. This is a positive driving force for the development of new urban areas and suburbs. Secondly, according to the analysis of TOD projects that combine specific urban functional spaces and economic activities, the railway network is beneficial to the space attributes and functional layout around the stations. It is worth noting that for different types of TOD projects, the manifestation of the effect is not the same. It shows particularity and differentiation. Decision-making about TOD is also more complicated because of its particularity and differentiation.

Key Words: Space Syntax, Multimodal Network, Accessibility Analysis, Spatial Configuration, Urban Structure, Railway Network, TOD Projects, PTALs, Statistical Analysis

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Chapter 1. Introduction

1.1 Background

Cities, especially metropolises, are faced with a series of complex problems caused by population agglomeration and proliferation of private cars, which do harm to the urban sustainable development and change behaviors of residents. Urban diseases such as traffic congestion, environmental degradation, lack of public space and suburbanization of work have not only reduced the quality of urban life, but also restricted the future development of the city to a certain extent. According to a report from the European Environment Agency (EEA), in 2018, 13% of carbon emissions came from cars in Europe.

In order to meet their inherent social and economic needs and improve the efficiency of transportation, urban strategies tend to transform the traditional car-dependent patterns of mobility into comprehensive public transportation, such as walking or cycling for short-distance travel and taking bus or subway for long-distance travel. The mode of planning, development and construction around the core public transportation hubs is defined as the TOD (Transit-oriented development).

Since the second half of the last century, the concept of TOD has been promoted in the field of urban planning and architectural design, and it has not gradually become one of the mainstream directions of related majors until it was introduced again by Calthorpe in *The next American metropolis*(Calthorpe 1993). Up to now, a large number of theoretical researches and practical cases about TOD have been studied. Although there are still many shortcomings in the early stage of concept development, with the development of science and technology and the continuous updating of related research, TOD has played an important role in urban diseases management. It has made significant contributions in alleviating traffic pressure, constructing compact cities and promoting regional connections.

At present, researches on TOD are mainly focusing on the level of traffic or building entities and they are hard to consider the impact of TOD on the nature movement of the city and the neglect multiplier effect caused by the station on the urban form and structure on a large scale. Space syntax theory proposed by Hillier and other scholars provide a different perspective for thinking about or evaluating the role of TOD models in cities(Hillier and Hanson 1984). Space syntax, as a method to analyze the statistical idea of movement according to the geometric morphology of urban space itself, could quantitatively map out the a probabilistic model of grid structure properties, thus demonstrating its status and function in the larger-scale urban structure by comparing the integration and choice degree of the TOD region.

1.2 Research Area

'There is perhaps no more potent or dramatic symbol of the Industrial Revolution than the railways'.

(Richards and MacKenzie 1986)

London, as a transport hub and one of the most influential cities for almost two thousand years. Since the establishment of the first subway track, Metropolitan Line(Figure 1), in 1863, London's public transport system has expanded and developed rapidly. It finally formed a dense public transport network (Figure 2), which is composed mainly of subways, railways, urban light rails, buses and other public transports. For a long time, these public facilities have been regarded as important places for coordinating the synchronous development of regions and displaying the modern image of the city. According to London Public Transport Statistics, the average commuting time in London is 47 minutes, and the average daily travel distance is about 7.4km (Figure 3). Moreover, during the non-pandemic period, the crisscrossed railway network has met the travel needs of nearly 30 million tourists and 7.8 million residents each year.

Since the 1980s, with the introduction of the legal responsibility for making railway operations financially profitable, TOD strategy has gradually become an important driving force for the internal development of London and the revival of the declining area.

The TOD strategies are called the "London Opportunity Zone" and other growth zones in the new London Plan (2021), which is the statutory Spatial Development Strategy for Greater London. In the Plan, TOD strategies have played an important role because a comprehensive investment plan that is integrated into the transportation system has developed to maximize the potential of the opportunity area.

Figure 1: Constructing the Metropolitan Railway Image from Wikipedia

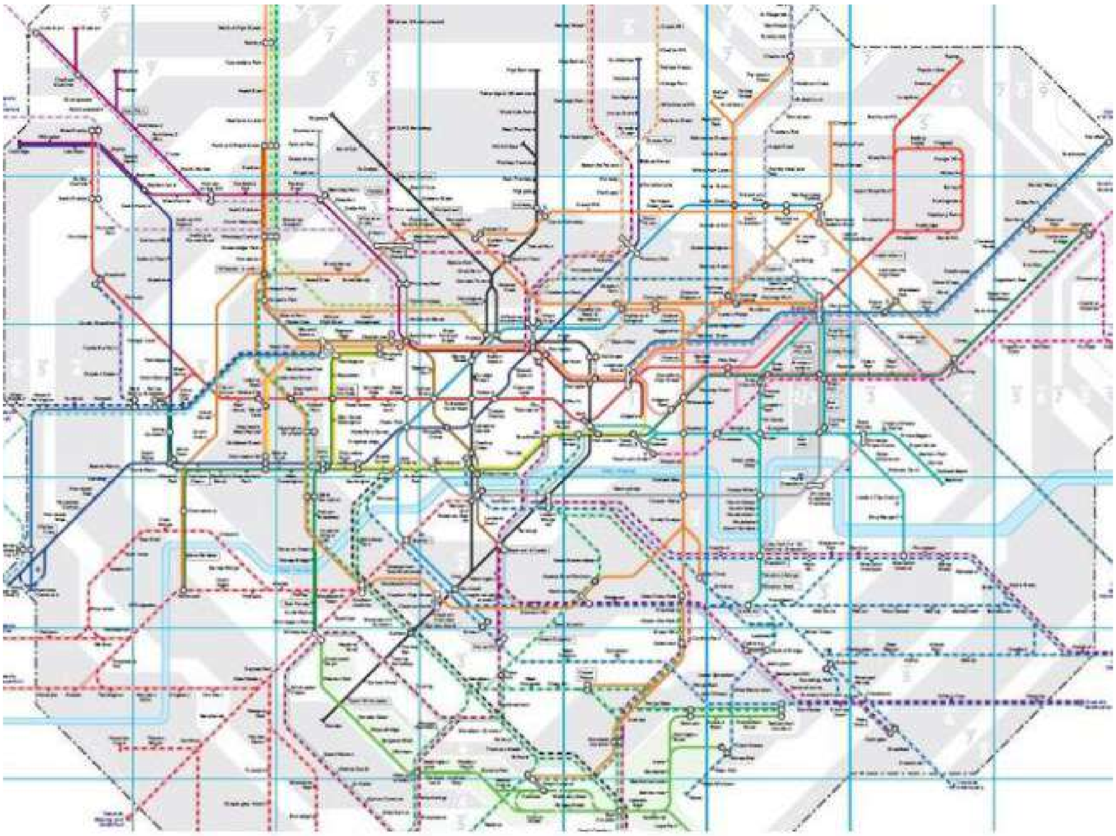

Figure 2: Schematic diagram of the rail transit system in Greater London

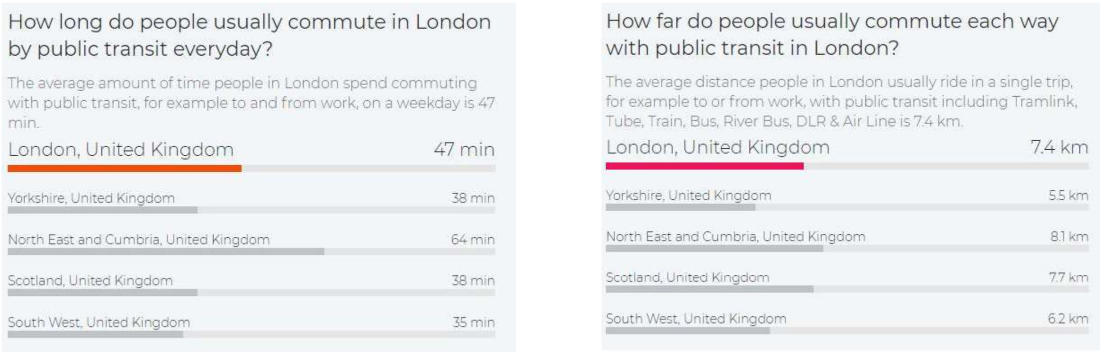

Figure 3: London Public Transit Statistics   Image from Moovit insights

1.3 Research Question and Hypothesis

In general, for research on railway stations or TOD projects, researchers usually estimate the radiation range of the station based on physical distance. So it is difficult to explain the impact of the railway network on urban development on the scale of the entire city. In the view of space syntax, the inherent economic attributes of the city and the movement of people and vehicles emerge from its spatial configuration itself. Therefore, the city should be regarded as a whole where the local changes will also affect the global results. On this basis, we could observe what role the railway plays in the city from a global perspective.

Then a hypothesis has been proposed: The spatial layout around TOD, which is part of the urban network structure, will have different influences on the city under different observation radii. This kind of influence includes not only the intuitive shaping and promotion of adjacent blocks, but also the abstract effect on the larger urban cyberspace.

Based on the above, this study mainly discuss the impact of public transportation systems on urban structure, clusters, and spatial accessibility. Research questions are phrased by two aspects:

1. How does public transportation influence the spatial accessibility of street-based network in London?

Aim: To explore how the public transportation layer affects the nature movement, spatial properties and the cluster structure of the city network based on the street configuration.

2. How does the urban strategy of TOD affect the space and social attributes around the stations?

Aim: To interpret the impact of urban design strategies under the guidance of TOD on the spatial configuration and microeconomic changes of the local area. Study how the city develops diversified and complicated functions around the station.

1.4 Dissertation Structure

Chapter one begins with emphasizing the importance of TOD strategies. Then it introduces the current public transport system and urban construction in London and proposes the next issues to be discussed from two perspectives. The second chapter discusses the theoretical significance of researching TOD by space syntax methods based on current literature. The third chapter combs the researchability of related issues and the specific methods of this work from a practical point of view. The fourth chapter describes the main analysis results on spatial accessibility, responding the first research question. The fifth chapter classifies TOD projects and examines the social and spatial characteristics around stations through cross-analysis of multiple data. The sixth and seventh chapter summarizes the core points of this research, reflects the limitations of the research and proposes possible directions for further research.

Chapter 2. Literature Review

This chapter will discuss and refine the characteristics and mutual influence of urban spatial configuration and socio-economic activities from the viewpoint of TOD, which is an importation development strategy of major metropolises, through the interpretation of existing literature. The focus of the discussion is first to explain the importance and inevitability of the TOD model in contemporary urban development. Then, it establishes a theoretical framework to describe the mapping relationship between natural movement and economic activities based on the related research of spatial syntax, and constructs the basic expanded structure of movement economy in cities through the quantified accessibility value. The following description is how the structure of public transport network affects urban street space, residents ' behavior preferences, regional economic development and how it is reflected in the spatial-temporal characteristics of the surrounding environment in the TOD area and the configuration grid. Therefore, this paper attempts to establish a theoretical basis to incorporate the public transport system into the analysis of the original street-based model, and explore the guiding role of TOD in urban development based on the new model by using the spatial syntax methods.

2.1 TOD Mode as an Important Feature of Modern Metropolis

International metropolises usually assume the role of high-level, high-impact and highly integrated political, economic and service centres. At the same time, many metropolises are still expanding outwards. For example, Shanghai has expanded its area tenfold since 1949(Tian et al. 2017), the number of private cars has increased by more than 200,000 annually since 2010 and The average number of subway passengers on working days has exceeded 8 million. With the emergence of sprawling cities, the costs of the movement are also raised, and a series of urban phenomena such as suburbanization of jobs have gradually emerged(Cervero and Landis 1992, Gayda et al. 2003). Since the last century, due to the increasingly complex urban system and the growing size of the city, scholars have put forward various theories and paradigms to alleviate and improve urban problems and guide urban development, such as urban regeneration and decentralized design(Carter and Roberts 2000, Sakieh et al. 2015). TOD (Transit Oriented Development) is also one of them. The success of projects in Hong Kong, Guangzhou, Tokyo, Copenhagen and other cities under the guidance of TOD theory also shows the importance of such planning strategies for cities(Cervero and Murakami 2009, Calimente and Use 2012, Knowles 2012).

The characteristics of TOD that can be summarized as advocating walking, giving priority to non-motorized traffic, creating a dense street network, connecting large-capacity public transport, and multi-hybrid, high-density and compact development. The general principle of TOD is to build a walk-friendly composite system around the rapid transit stations, usually with a radius of 400m to 1200m to establish a comprehensive plan with business, education, leisure, housing, and culture services, so as to create a safe and comfortable 15-minute life circle(Cervero, Ferrell, and Murphy 2002, Belzer and Autler 2002). In the whole world, TOD has been seen as a comprehensive strategy to address or improve ' urban diseases ' such as traffic congestion, single land use type, unreasonable resource allocation and lack of walking space(Lyu, Bertolini, and Pfeffer 2016). TOD-centreed urban planning promotes compact urban development by encouraging low-carbon travel, coordinating land use, creating livable communities, and ultimately achieving the goal of creating sustainable urban development areas with high quality, high value and high accessibility.

Through the research and evaluation of the completed TOD project, this kind of strategy has been proved to be effective and consistent with sustainable development to a certain extent(Galelo, Ribeiro, and Martinez 2014, Singh et al. 2017). It has a positive impact on urban public environment, traffic structure and social-economic activities. After evaluating the TOD operation situation of 50 cities in China, the results show that the total area of the TOD projects developed in China has shown a significant upward trend. In addition to the first-class cities, second-class and third-class cities have huge markets to adopt public transport-oriented development strategies(Xu et al. 2017). Other studies in recent years have shown that in many regions, including Washington, D.C., California and Baltimore metropolitan areas(Cervero 1993, Arrington and Cervero 2008), car ownership and utilization of households living near railway stations have also been significantly reduced. This is not only determined by the distance between the stations and the settlements, on the contrary, many analysis shows that it is not even the main reason. Comprehensive planning for high-density residential development, restrictive parking management and diverse land use are the reasons to reduce private car travel in many cases(Nasri and Zhang 2014). In other words, the TOD mode is a regional development strategy, not a simple transportation plan(Kralovich 2012). Such as the new London Plan mentioned above. In the context of globalization, TOD is gradually considered as a politically popularized planning concept to promote regional compact development(Thomas et al. 2018).

2.2 Natural movement as a by-products of spatial configuration

Space syntax is a theory that abstracts space into topological connection, so as to quantitatively analyze accessibility and closeness of this topological relationship(Hillier and Hanson 1989). For the reflections on urban space, street-based network configuration has always been the focus of urban planning and geography researches(Griffith 2011). However, most traditional views regard the street as a material background with spatial-temporal attributes used to carry the activities of residents(Scheer 2001). The street itself does not have the connotation of reflecting social and economic information(Girling and Helphand 1996, Jacobs 2016, Xie and Heath 2017).

But some researchers hold different opinions. Hillier, Hanson and Penn think that the geometric configuration of urban street network itself is an important factor affecting the movement distribution of people and vehicles. They call it the theory of urban '*natural movement*', which is one of the core concepts of space syntax(Hillier et al. 1993). When the initial spatial network emerges, the differences in different regions appear according to the level of accessibility. Considering the influence of people's subjective decisions on the form and use of space, these high accessibility areas are naturally endowed with higher land value and potential in the next stage of urban development. This advantage will bring higher density of construction, so as to gather more intensive flow, and those low accessibility areas may be the opposite. This kind of network configuration with natural movement attributes has an interaction with socio-economic factors, and urban structure has been shaped by the dynamic cycle of this interaction for a period of time. This phenomenon is called *'multiplier* *effect'*(Hillier et al. 1993, Penn et al. 1998). As a result, cities are not a mixture of independent social behaviour and spatial patterns, but should be seen as '*movement economy*' associated with physical and spatial structures(Hillier 2007).

It is this unity that makes ' accessibility ' an important reference indicator for us to understand the current urban form and predict the future urban development trend rationally(Can and Heath 2016, Legeby 2010). In the practical application of spatial syntax theory, accessibility is mainly represented by the value of choice and integration. Regions with high integration degree mean greater probabilistic population flow and socio-economic activities(Hillier and Hanson 1989)(1984), and segments with high choice degree mean the potential of being selected as the optimal path(Hillier et al. 1986). There is already a source of value embedded in these environments, and things related to TOD could be the spread this kind of value.

Although space syntax theory has been criticized for oversimplifying and theoreticalizing complex urban problems in the early stage(Jiang and Claramunt 2002, Batty 2010), with the updating of research method for topology configuration(Turner 2004, 2007) and the related spatial network analysis of more than 20 cities(Hillier, Yang, and Turner 2012), the accessibility analysis based on angle change is considered to be more accurate than metric-based and topology-based methods in reflecting the movement state of urban space(Hillier and Iida 2005). In the global system, angular choice consistent with actual condition better than local areas, where the angular integration reflects the actual aggregation of economic activity better(Hillier et al. 2009). Therefore, natural movement can be considered as a probabilistic by-product of spatial configuration extracted from the network geometry, and the spatial accessibility which can be quantified to reflect the movement distribution is an important basis to describe the urban structure.

2.3 Multi-modal Based on Space Syntax as a Tool to Study TOD

Most of the analysis results on accessibility can be regarded as street-based(Hillier and Hanson 1989). In recent years, most researches on cities based on spatial syntax have analyzed topological relations in axial map(Turner, Penn, and Hillier 2005) or segment map(Turner 2004), which is a model that can reflect urban street space more accurately than road centerline. However, some scholars believe that public transport, especially railways and subways, will also affect the structure of urban network configuration(Chiaradia, Moreau, and Raford 2005, Schwander 2007). Given that cities such as London, Shanghai and Tokyo already have more than 5,000,000 subway passengers per workday, the impact of this ' invisible ' travel mode on movement distribution should be given more attention in the next study. In addition, even buses running on the ground are different from agents that can move freely because they have fixed lines and stations and no longer have continuous path choices.

At present, there has been some attempts to study TOD under space syntax theory. Chiaradia, Moreau and Raford(Chiaradia, Moreau, and Raford 2005) demonstrated that the movement distribution of the metro network was affected by topology configuration similar to that of the ground street by modelling the London underground and overground street separately. Meanwhile, the usage of the station is related to the topological configuration of the metro network and the spatial accessibility around the station on the ground. Then Schwander(Schwander 2007) constructed the bi-model, which combines the regional centre with the underground network, and proved that the bi-model was more accurate than the single underground network model in reflecting the impact of rail services on urban structure by comparing with empirical data.

Gil(Gil 2012) and Law et al.(Law, Chiaradia, and Schwander 2012) further added the railway layer to the traditional street-based network through the interface (mostly representing the entrance and exit of the subway station), forming a new multi-modal map, which different layers can be given different weights. This kind of non-traditional model has been proved to better explain the socio-economic activities around the stations and the distribution of urban integration centres than the street-based axial map. Subsequently, Gil(Gil 2014) incorporates more analytical indicators into multi-modal networks, including public transport, private transport, land use and interfaces between them, aiming to create a unified model to measure accessibility of urban networks covering multiple motion patterns, contributing to suggestions and references for urban planning or design.

Yang and Qian(Yang and Qian 2021) adopted the method of sDNA(Cooper and Chiaradia

2015), which is acknowledged as an effective means to analyze the traffic network, to study the subway network and surrounding environment in Beijing from the aspects of closeness and betweenness(Cooper 2015). The conclusion shows that as the research scope expands from local to global, the multiplier effect of the subway network is becoming more and more obvious, which leads to more concentrated in some regions and more isolation in other regions. Moreover, some scholars argue that transfer between public transport increases time, distance and even psychological costs. One of the manifestations of psychological cost is that according to questionnaires, most passengers are more willing to choose a plan that does not require transfer(Chiaradia, Moreau, and Raford 2005, Jun et al. 2006). However, due to the complexity of modelling, in the study of large-scale urban space, this transfer cost is usually ignored to simplify the multi-modal map(Gil 2012, Law, Chiaradia, and Schwander 2012). Therefore, multi-modal network can be used as a more effective and precise model to study the configuration of public transport and characteristics of TOD development zones.

2.4 Literature Review Summary

To sum up, the measurement and evaluation of TOD are of great significance for understanding the current urban form, solving multiple problems and guiding future development. Space syntax, as a research method and thinking dimension different from traditional transportation and geography, can help researchers rationally understand the interaction between public transport network, urban spatial configuration and residents ' daily life practice from both quantitative and qualitative perspectives.

However, most studies on TOD based on spatial syntax theory are still in its infancy, and there is still no widely acknowledged evaluation system and standard model, and Table 1 is the contribution of existing literature to related research issues. In the next stage, this research will analyze the spatial accessibility of the multi-modal network and correlate the socio-economic data of the TOD area. Then discuss the influence of rapid transit system on the city configuration attributes and the role of TOD projects in shaping the local spatial forms and guiding the distribution of functions.

Year	Author	Contribution
2005	A Chiaradia	For the first time to analyze the London railway network using the technical means of space syntax
2006	C Jun, JH Kwon, Y Choi, I Lee	Space syntax theory is used to describe the accessibility of public transportation stations by calculating the O-D optimal path.
2007	A Chiaradia	By extracting main railway junctions and urban centers, a possible network analysis method based on space syntax is proposed to incorporate the railway network into the urban configuration.
2012	J Gil	Built a multi-modal system, unify the railway network and streets in a map for analysis and analyze the corresponding spatial accessibility
2012	S Law, A Chiaradia, A Schwander	Developed a multi-modal network that combines the railway network with the street, and validated the model through socio-economic data.
2014	J Gil	Continue to develop the Multimodal Urban Network model, combining various transportation infrastructure networks including pedestrians, bicycles, cars, buses, trams, and subways with the city's basic street network.
2020	C Yang and Z Qian	Analyze the impact of the Beijing subway system on the configuration of the ground network, and believe that the angular metric can better describe the mixedurban form
2021	P Song（The author）	Analyze the impact of the public transportation system and TOD projects on the spatial accessibility and configuration properties of both city and station surroundings on the basis of the multi-modal network.

Table 1: The contribution of existing literature based on space syntax theory to research on public transportation system and urban networks

Chapter 3. Methodology

3.1 Introduction and Main Method Flow

This chapter introduces a new multimodal network which adds a railway layer to replace the traditional street-based network. The purpose of constructing the new model is to reflect the influence of railways on spatial accessibility and global network structure through comparison with the original model. Then the attributes and characteristics of spatial configuration around the stations have been figured out.

Concretely, the method design includes the following steps:

Sort out the London railway network and connect different stations in straight lines to form a complete topological network.

Construct a multimodal network and test its closeness and betweenness in Depthmap. Quantitatively analyze the impact of the railway network on urban space.

Analyze the change trend of the spatial configuration and spatial accessibility around the stations, and discuss the stimulus effect of TOD on urban development in different categories.

3.2 Collection and Limitations of the Dataset

3.2.1 Railway Network of London

The rail transit system in London mainly includes the Underground, Overground, National Railway and Tram. In addition, it also includes the Heathrow Express and TfL Rail between Paddington Station and Heathrow Airport as well as the unmanned track system DLR located in the east of London.

The main source of data for railway stations is The UK Ordinance Survey. A total of 674 stations were selected for this study, which basically covers the entire Greater London area (Figure 4). The railway track mainly refers to the Open Street Map, and is partially optimized according to Google Map, Ordinance Survey and Tfl. According to the analysis result of Kernel density estimation (Figure 5), the stations are not distributed evenly. The closer to the geometric centre of the city, the higher the density of the stations, and about half of them are distributed in inner London. Even in inner London, a large number of stations are still located north of the Thames. However, in the southern area of Greater London, at the junction of Bromley and Lewisham, Merton centre, Croydon centre, the station distribution forms some small clusters which have higher density than other areas significantly.

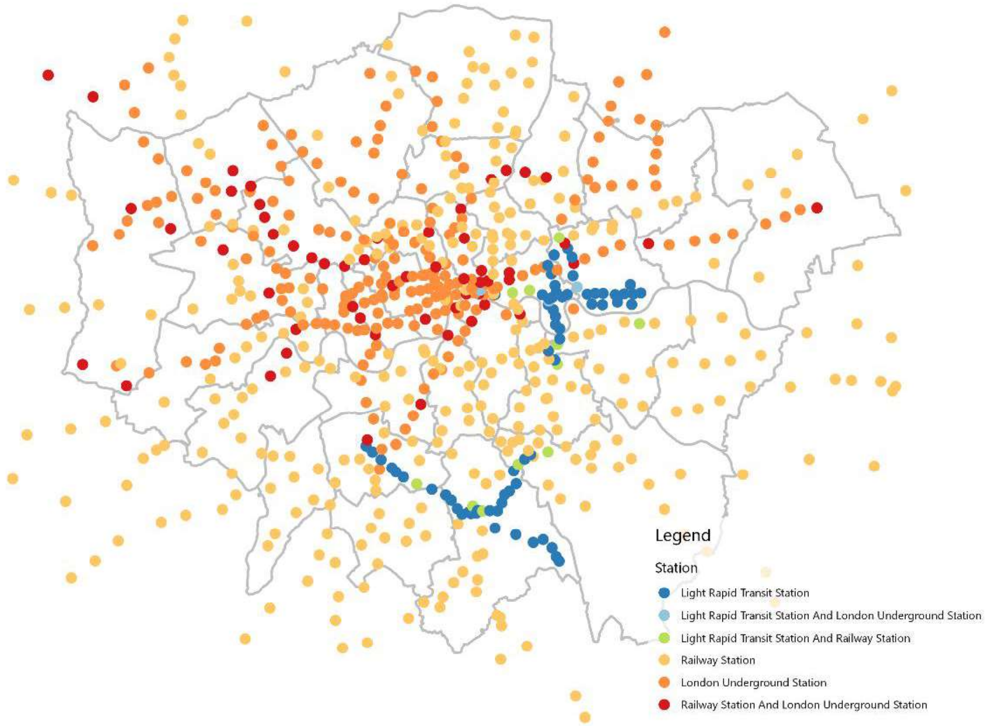

Figure 4: Station distribution

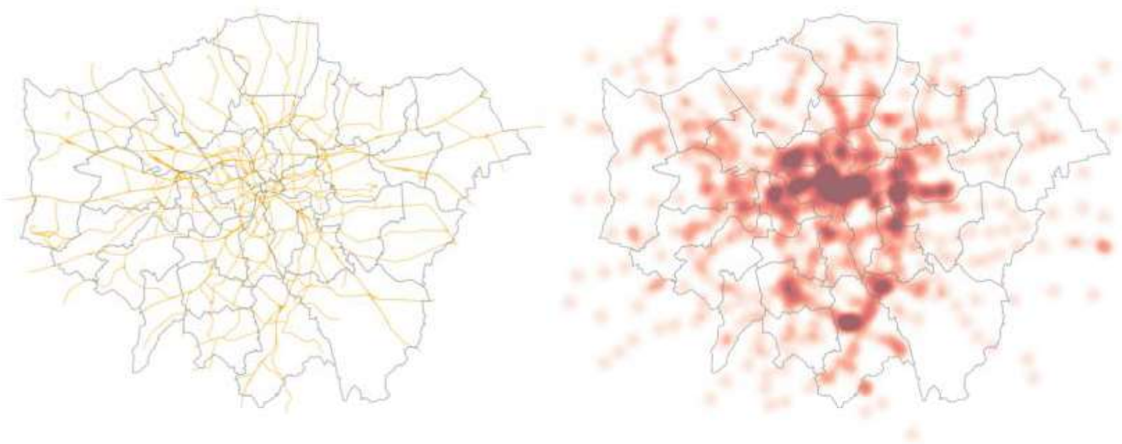

Figure 5: Railway track and Heat map of station

It’s found that passengers tend to pay more attention to specific origin and destination of railway stations. Their perception of angle and distance changes between stations is blurred relatively. Especially in the subway, it is more difficult to judge the detailed location during the journey due to the inability to obtain the view from the train windows. Therefore, referring to the method of Schwander (2007) and Gil (2012), the railway network is abstracted as a topological structure composed of scattered points (stations) and lines between them. Then we can simplify the curved railway track into a straight-line network model.

In addition, the railway network is not just a direct connection between different stations (Figure 6), but a system that allows parallel lines (Figure 7). In the light of Tfl's latest 2020 London Underground route map (Figure 2), We can connect stations more than one time according to different routes to ensure a more accurate reflection of passengers' actual travel choices (Figure 8).

Figure 6: Single-line link of Stations

Figure 7: Multi-line link of Stations

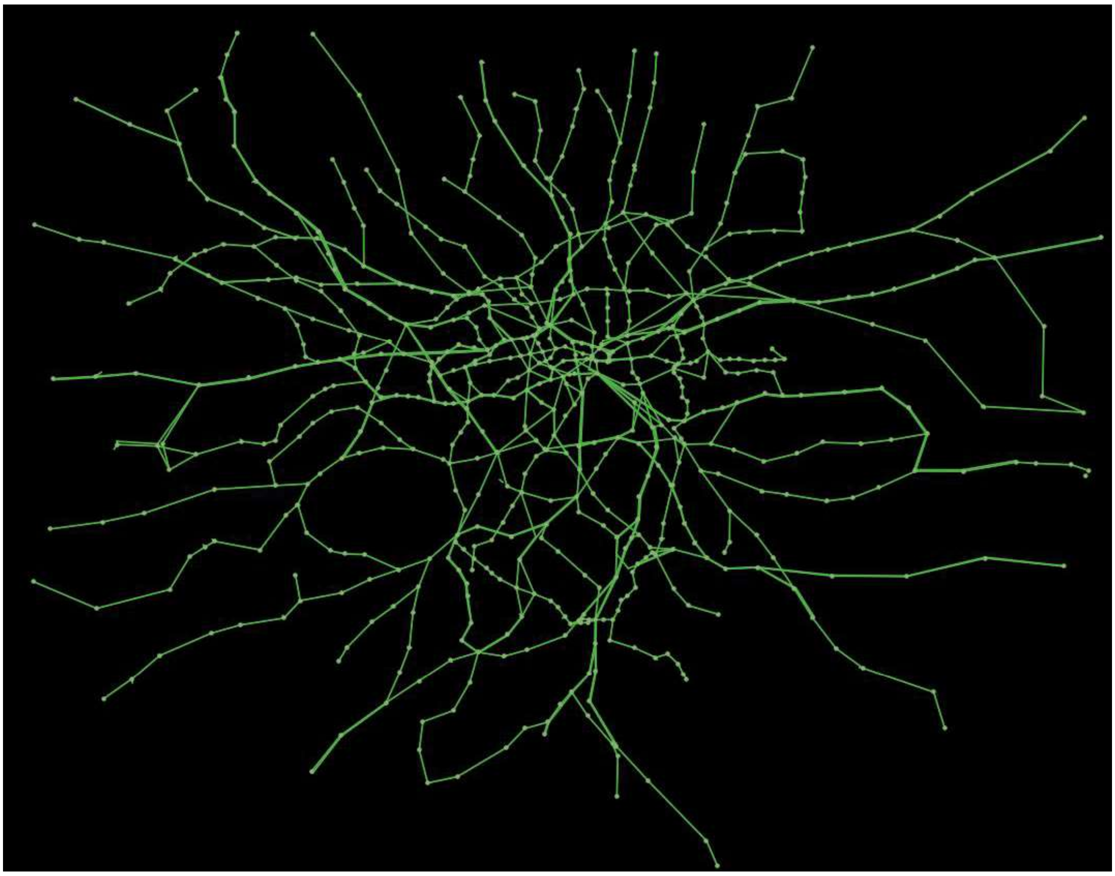

Figure 8 Railway network with multi-line links

3.2 2 Limitations of the Dataset

It is important to note that the new railway model still has certain limitations which are mainly caused by the modelling method which is similar to the topological structure.

Firstly, the reduced accuracy of the simplified model in terms of distance and angle changes is mainly due to the deformation in the process of converting from curves to straight lines. So the more winding the original track, the higher the inaccuracy. Moreover, changes in distance and angle will slightly distort the results of the subsequent spatial accessibility analysis in DepthmapX.

Secondly, the new railway network is a theoretically uniform speed system, that is, paths with the same distance by default take the same time. However, in reality, the time consumed by railway transportation is mainly composed of traveling time and immobile time at the station. Considering the acceleration mechanism of the train itself, the longer the distance between the two stations, the faster the average speed. This part of the difference has been deliberately simplified in this study to avoid overcomplicating the analysis method.

Thirdly, the time and distance costs for passengers to transfer between different routes are omitted. In the ideal model, different routes passing through the same station are considered to be directly connected, but actually this kind of transfer takes a certain amount of time and walking distance.

Due to the above limitations, the model in this study has certain deficiencies and defects, but given the operability and comprehensibility of the analysis, appropriate simplification is still necessary. The optimization of the railway model may be carried out in future research.

3.3 Spatial Accessibility Analysis of Multimodal Network

3.3.1 Establishment of Multimodal Network Model

The railway network layer constructed in the previous section is used to measure the impact of public transportation on urban spatial configuration and mobility. Since the new layer is also composed of lines and nodes, so in the new multimodal network model (Figure 10), it can be combined with the traditional London M25 segment network (Space Syntax Ltd) by creating a connection similar to 'modal interface' (Gil 2012).

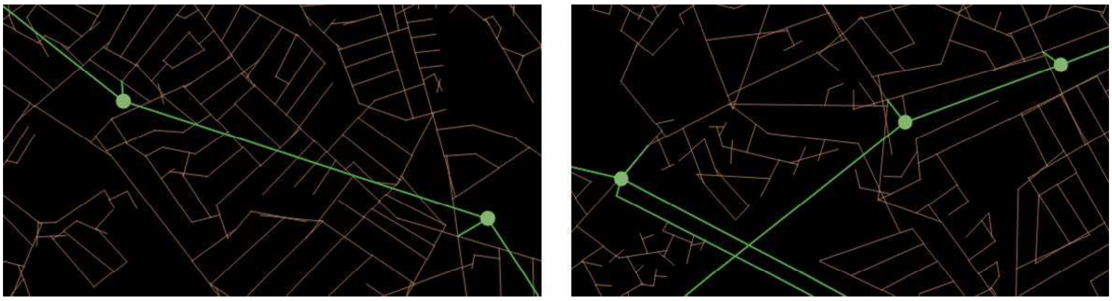

Figure 9: Combination of railway layer and street layer

Figure 10: Multimodal Network of London 25

Taking into account the difference walking and taking the subway, it is necessary to assign weights to the street layer and the railway layer by travel speed. As it’s mentioned in the literature review that the TOD model encourages people to walk in short distance and take public transportation in long distance. Hence, the weight of street network refers to walking speed (4.8km/h), and the weight of railway network refers to train speed (36km/h).

3.3.2 Space Syntax Analysis of Multimodal Network

In recent years, many disciplines, including geography, transportation, and urban planning, have continuously developed analytical methods for network structure, such as sDNA analysis(Cooper and Chiaradia 2015), O-D analysis based on genetic algorithms(Jun et al. 2006) and segment angular analysis(Turner 2004). The space syntax software, DepthmapX, which is developed by Varoudis and Turner, has been used to quantify the accessibility and cluster structure of the multimodal network in London by calculating integration and choice value. Recent studies have shown that the normalized angular integration value and angular choice value with the radius type of metric has been proven to be a more accurate way to reflect the movement of people and vehicles in the city(Hillier, Yang, and Turner 2012).

Given that the average distance between London railway stations is 1.5km, and in some areas it can even exceed 3km, this analysis focuses on the radii from 1600 to 20000 meters. Moreover, in the case of a radius of n, the analysis has also been specially performed for obtaining a more holistic network configurational structure. Due to the edge effect, the radius of n appears to be particularly problematic. The same operation was conducted on the original street model so as to compare with the new multimodal network and get the change trend of the regional network centrality under the influence of railway traffic.

Since the change of any line segment will affect the analysis results of spatial accessibility, in order to compare different models, we need to normalized them to eliminate the effect of the number of elements in the graph from the total depth and/or choice calculations. In the following, **NAIN** stands for *normalized integration value* and **NACH** stands for *normalized choice value*.

3.3.3 Comparison of PTAL Values and Spatial Accessibility

Public Transport Accessibility Levels (PTAL) is a metric that has been widely used in the UK, especially London, to describe the connectivity of a local area to the public transport system. In the beginning, it was developed by the London Borough of Hammersmith and Fulham(Abley and Williams 2008). This methodology divides the region into different squares at intervals of 100 meters, and then calculates the PTAL value of each 100-meter square through a comprehensive analysis of parameters including the distribution of public transportation stations, service frequency, walking distance, and waiting time (Figure 11). The advantage of this method is to use PTAL values to directly generate intelligible color contour maps, which can help users make decisions on this basis more clearly. Up to now, PTAL has been deeply applied to various urban planning and development strategies, such as The London Plan and Opportunity Area Planning. Since the concept of closeness or integration in the spatial syntax in this study is also expressed as 'spatial accessibility', in order to prevent ambiguity, the ability of different areas to connect to each other through the public transportation network is expressed as 'PT-connectivity'.

This research superimposes the integration map of the two models with the PTAL map, analyzes the relationship between the spatial accessibility of the network configuration and the PT-connectivity of public transportation. Based on the comparison of the areas with high accessibility and the places covered by high PT-connectivity, this study would discuss the advantages of space syntactic analysis based on multimodal network for further in-depth study of movement and activities in cities.

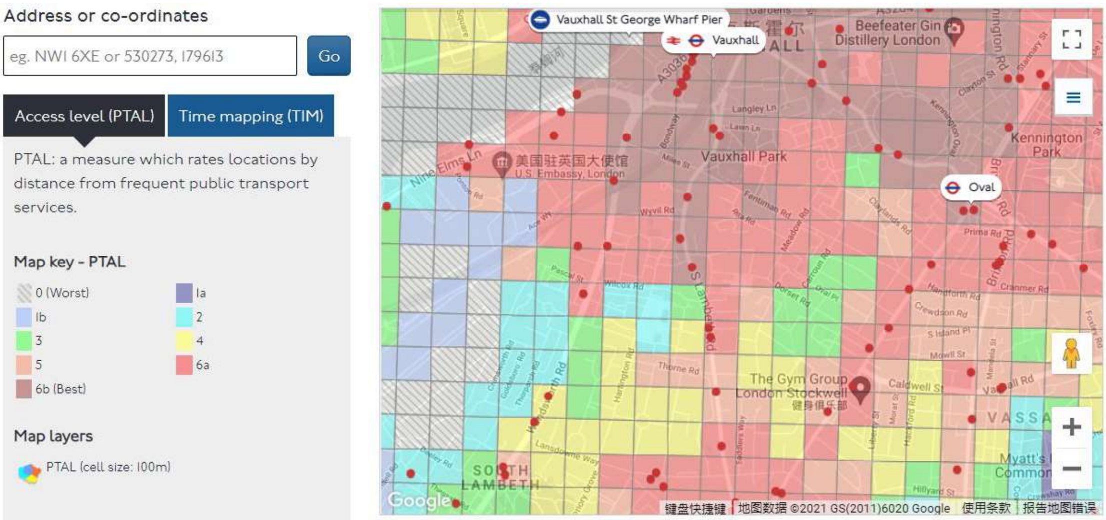

Figure 11: PTAL map on WebCAT Image from WebCAT

3.4 Space configuration analysis around the station

3.4.1 Catchment Analysis

In order to further understand how the TOD strategy works in the area around the stations, it is necessary to define the boundary of the influence area according to the distance to the stations firstly. Instead of use the traditional concentric circle pattern buffer, this paper draw the catchment area cropped by the distance from the midpoint of each line segment to the station. Catchment analysis is completed in QGIS by Space Syntax Toolkit(Gil et al. 2015), which is a user-friendly front-end window for DepthmapX software. The research focused on analyzing the change trend of spatial accessibility in the catchment area within 2000m.

The spatial distribution of POI is also used to compare with catchment areas. The *join attributes by location* function is used in QGIS to filter out POIs with different distances to the stations. In general, 400m is considered to be the distance that people can reach by walking for 5 minutes, so the analysis radii is set to 400, 800, and 1200 meters to correspond to the 5-minute life circle, 10-minute life circle, and 15-minute life circle in the TOD strategy respectively.

3.4.2 Analysis of Categorized TOD Projects

On the basis of the above analysis, combined with location, function and positioning, the TOD projects in London are categorized and their characteristics are summarized. Each category achieve a better understanding of the spatial accessibility and socio-economic attributes of the configuration around the station by case studies.

Firstly, according to different radii in space syntactic analysis, a series of integration values and road network density of the multimodal network are obtained.

Secondly, land use, which is an important data indicator reflecting the local socio-economic attributes, has been compared to observe the similarities and differences between different classifications of TOD projects.

Thirdly, Google Street View is used to gain a qualitative perception of different projects and better understand the differences.

Chapter 4. Spatial Accessibility Analysis of Multimodal Network

This chapter answers the first research question by analyzing and describing the syntactic value of the spatial line segments, discussing how rail transit affects the spatial accessibility of the street network, and how much influence it has on the distribution of the integration structure.

4.1 Analysis of the Spatial Accessibility and Difference of Multimodal Network

By using related software of space syntax and QGIS, segment angular accessibility can be expressed quantitatively and visually. Figure 12 demonstrates the degree of central integration of London in the context of global analysis. The red area represents its spatial configuration with a higher integration value, which means it has more active micro-economic activities. And the blue area represents lower integration values which means the urban space is looser and the possibility of encounters is lower.

Figure 12 describes the integration result of the original pedestrian network while Figure 13 reflects the integration result of the weighted multimodal urban network. Observing Figure 12, we can find that the most active area is located in the Central Activities Zone, which is in line with most people's perception. The high-integrated network structure diverges radially around the core area, and two horizontal and two vertical extension axes based on A10, A5, A40 and Romford Rd are formed in the north of the Thames respectively. And along A40 Rd and its adjacent areas, a development belt that runs through Westminster, Kensington and Chelsea, Hammersmith and Fulham is formed. Although the structure to the south of the Thames is not clear to the north, it develops linearly generally.

Then Figure 13 demonstrates that the area with the highest integration value in London is still located in the international centre including the City of London, but the way it radiates outward has undergone some changes. In addition to linear diffusion along established streets, some new scattered high concentration line segments have appeared. This phenomenon is particularly obvious in the south of the Thames and parts of the outer London area. Such as Wimbledon Chase, Brockley and Sydenham stations.

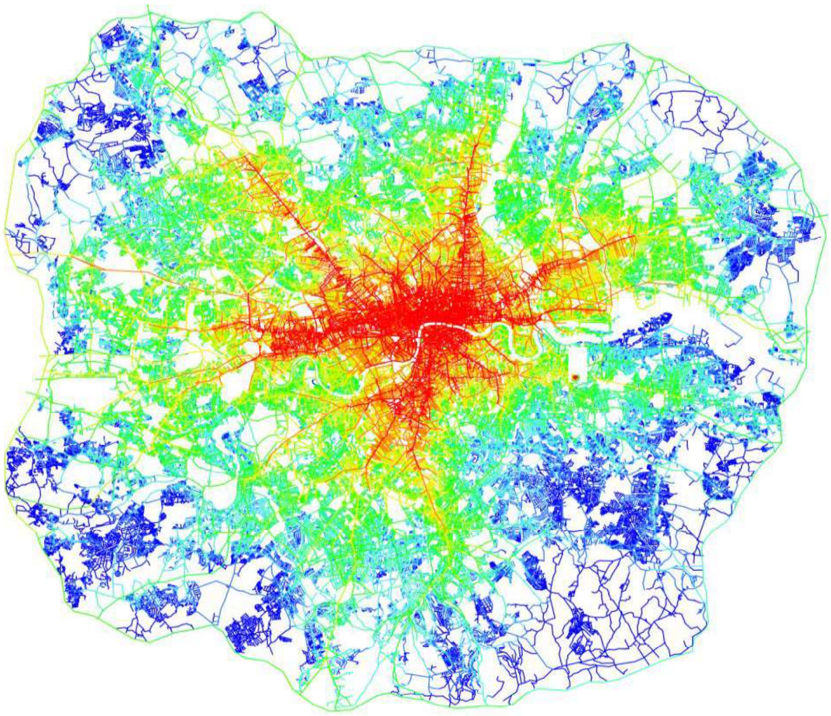

Figure 12: Global segment angular integration of street-based network

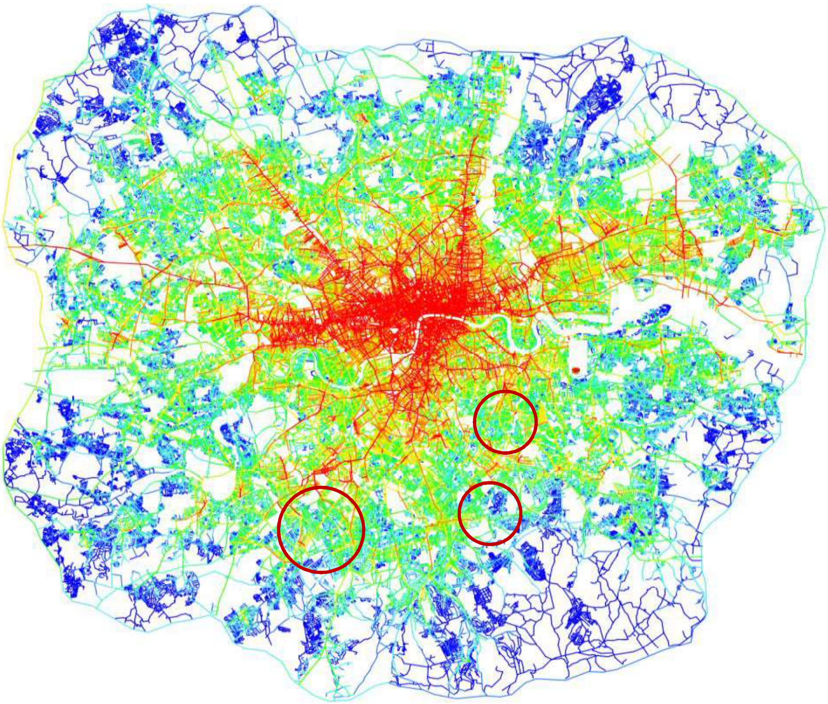

Figure 13: Global segment angular integration of multimodal network

Observing Figures 14 to 18, we can get a conclusion that the larger the radius of the calculation, the more important the influence of railway traffic on the urban structure. In the case of a smaller analysis radius, the impact of the railway layer on the integration measurement of the local configuration could be almost ignored. For example, the outputs of multimodal map and street map are almost the same under 1600m and 3000m radius. This is mainly because there is a certain distance between difference stations. As mentioned above, the average distance between adjacent subway stations is about 1.5km, so the difference in urban structure between the two models is not clear when the radius is relatively small. However, as the analysis radius increases, the influence of the railway layer on the street layer is gradually expanding. The spatial accessibility under 5000m (Figure 16) still has a very high degree of similarity, while the integration of the south of the Thames and the east of Greater London under 10000m is somewhat improved. The most obvious result of the difference appears under 20,000m and the radius of n. The spatial integration value of the Greater London South area, including Barking and Dagenham, Havering, Bromley and Lewisham, has increased to a certain extent. The impact of the railway network on the city has gradually expanded from the city centre to the middle and even peripheral areas of the city.

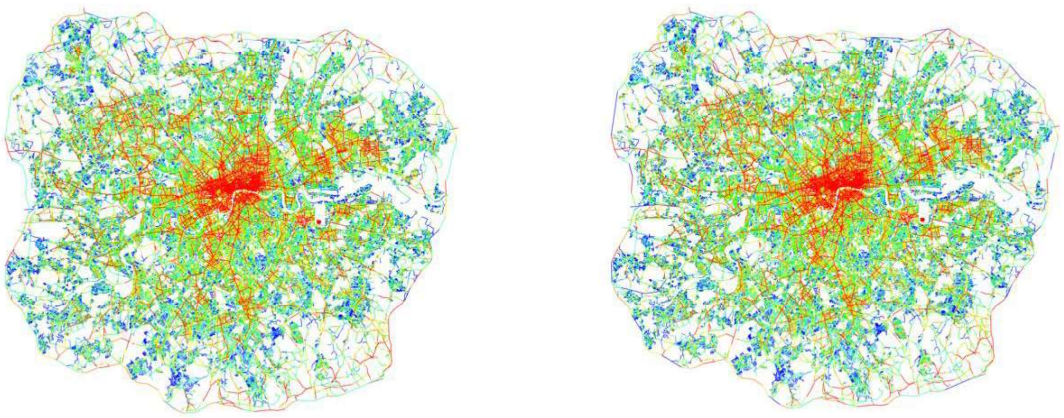

Figure 14: Integration of street-based network(left) and Integration of multimodal network (right) Radius: 1600m

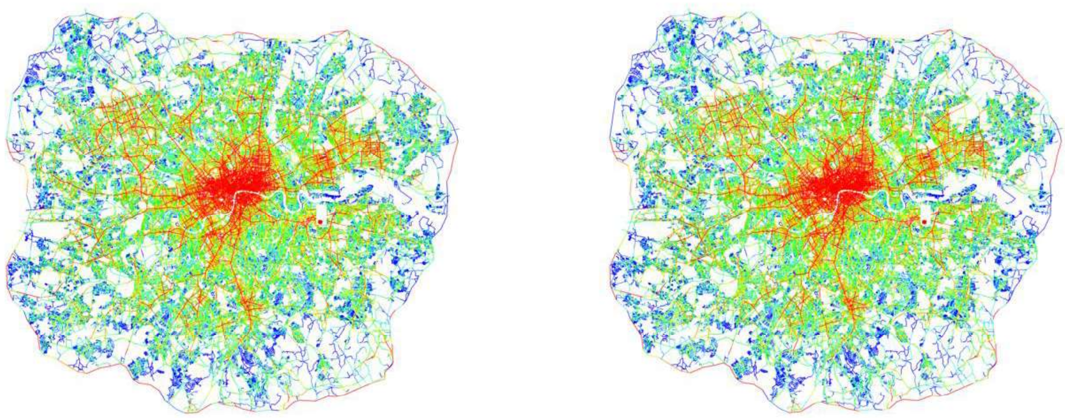

Figure 15: Integration of street-based network(left) and Integration of multimodal network (right) Radius: 3000m

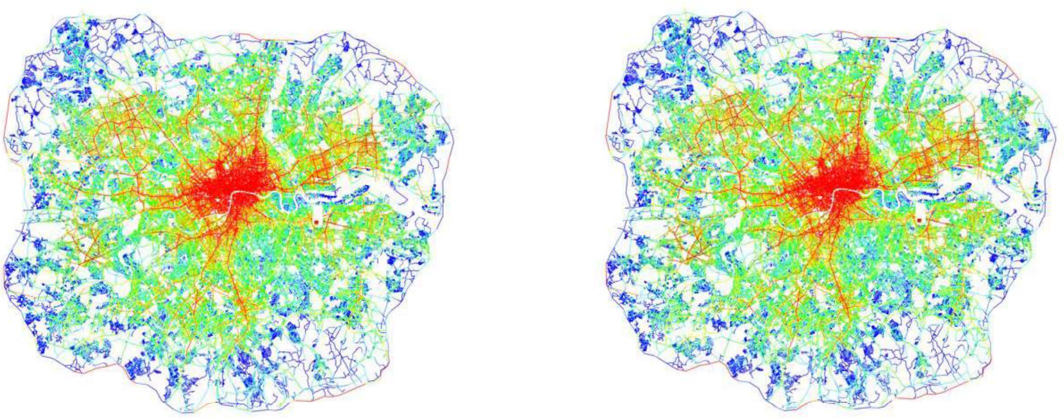

Figure 16: Integration of street-based network(left) and Integration of multimodal network (right) Radius: 5000m

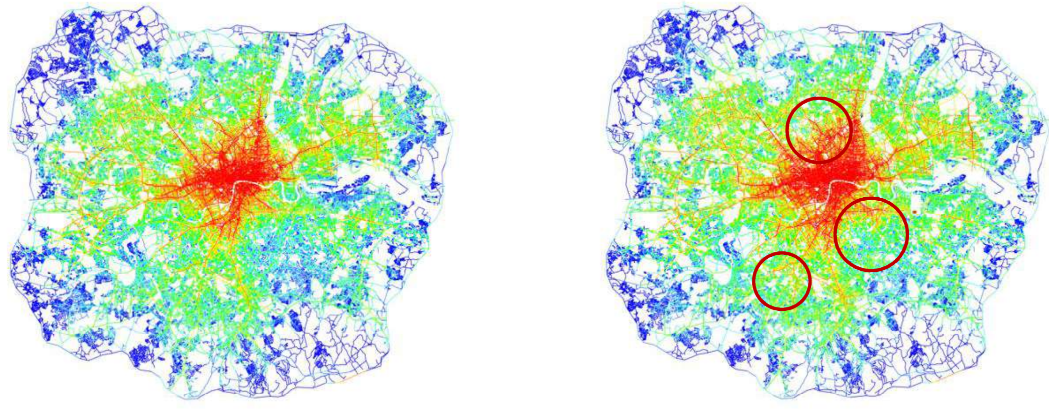

Figure 17: Integration of street-based network(left) and Integration of multimodal network (right) Radius: 10000m

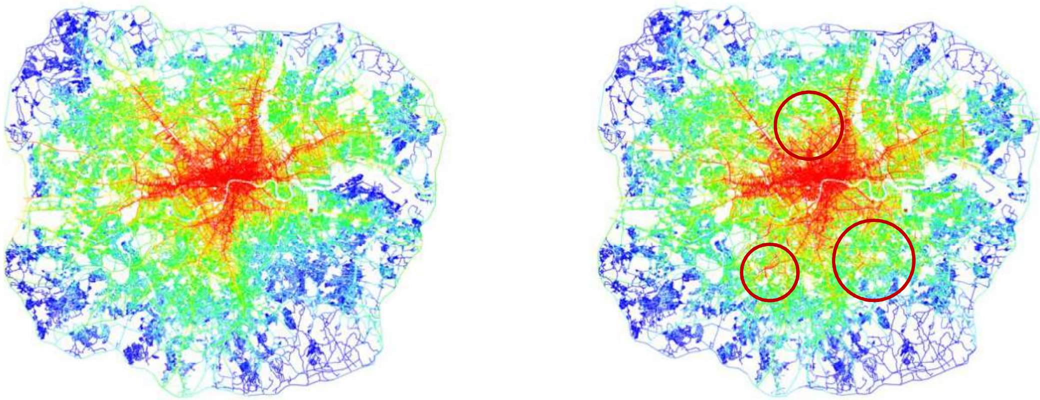

Figure 18: Integration of street-based network(left) and Integration of multimodal network (right) Radius: 20000m

Next, by visualizing the difference between the analysis results of the two models, we can more clearly observe the role of the railway network in the spatial accessibility of urban streets. Figures 19 to 24 (left) are the the difference maps of integration values between multimodal map and street-only map under different radii respectively. The darker the red represents the greater the difference, it also means that the greater the potential for improvement in the regional integration ranking after railway traffic is taken into account. The darker the blue, the smaller the difference, which means that the area is less affected by the weighted multimodal network. Filtering out the top 10% line segments (black) from the difference maps and superimposing them with the heat map of the railway station can help us analyze the relationship between the spatial coordinates of the station and the integration difference.

Figures 19 to 24 (right) are superimposed images under different radii. Under the analysis radius of 1600m, the network integration near the station has been significantly improved, which shows localized characteristics. The structure of the integration (hereinafter referred to as *structure*) enhancement area covers the entire Greater London area along the railway track basically. Under the analysis radius of 3000m, the *structure* is more compact than that of 1600m, has a tendency to shrink toward the inside. And it is very consistent with the heat map of the railway station. Local areas with densely distributed stations also have greater development potential, such as the areas north of the Thames that mainly include the City of London, Westminster, Camden, and Tower Hamlets. However, under the analysis radius of 5000m, the *structure* did not compress further, but diverged slightly from the city centre. The result is still similar to the heat map of the railway stations. In addition, more lines appeared south of the Thames or near Greenwich Station.

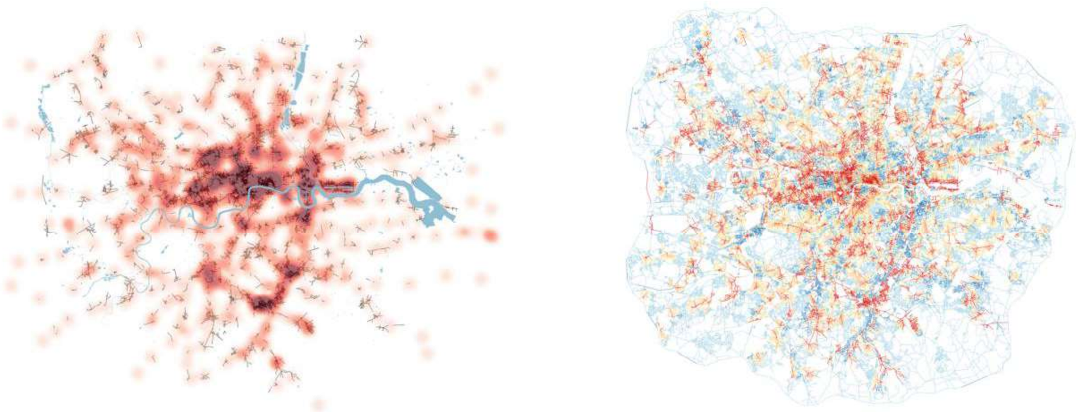

Figure 19: Top 10% of the difference (left) and Difference map of integration (right)   Radius: 1600m

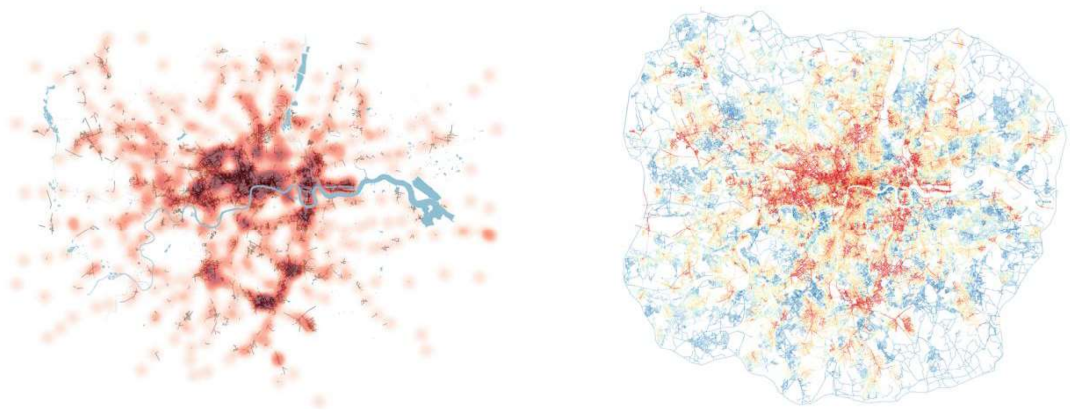

Figure 20: Top 10% of the difference (left) and Difference map of integration (right)   Radius: 3000m

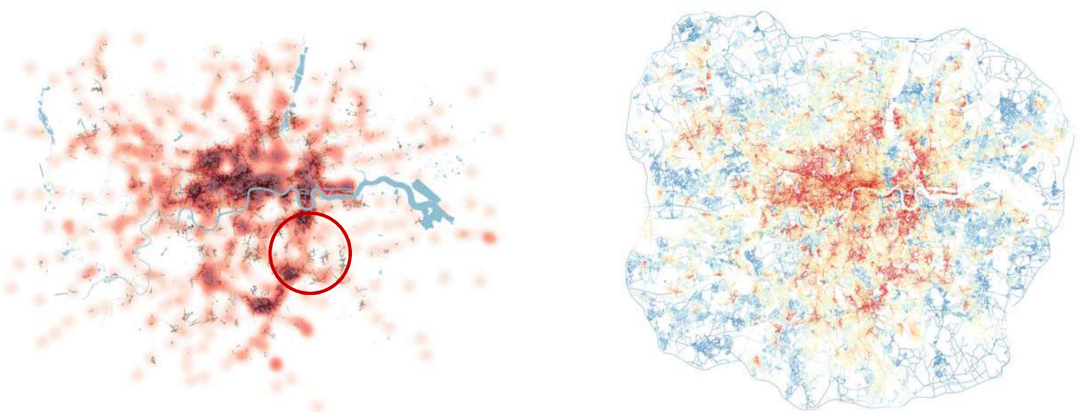

Figure 21: Top 10% of the difference (left) and Difference map of integration (right)   Radius: 5000m

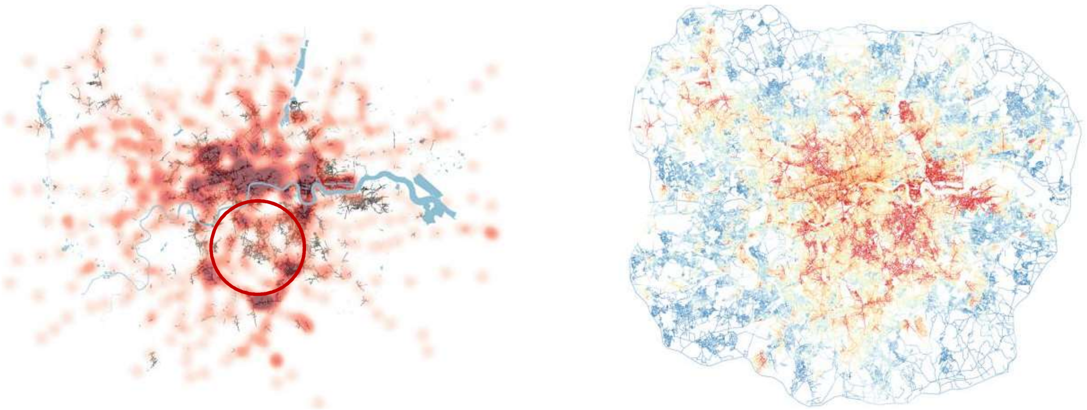

Figure 22: Top 10% of the difference (left) and Difference map of integration (right)   Radius: 10000m

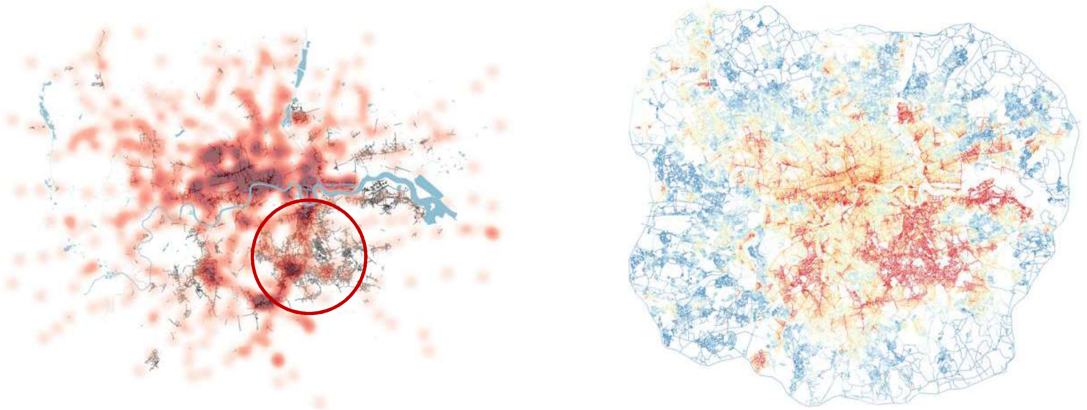

Figure 23: Top 10% of the difference (left) and Difference map of integration (right)   Radius: 20000m

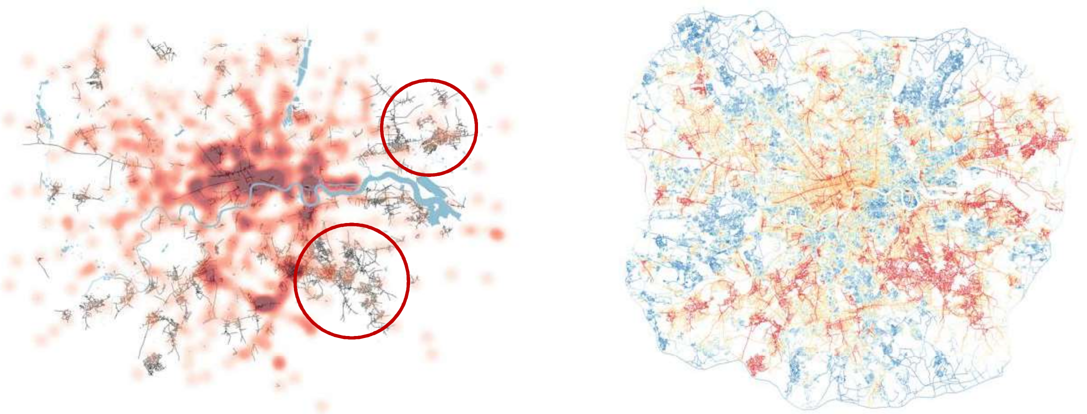

Figure 24: Top 10% of the difference (left) and Difference map of integration (right)   Radius: N

Then as the radius expands to 10,000m, the *structure* is further decentralized and shifted to the southeast of the city. The potential to increase the spatial accessibility of the city centres such as Westminster and Camden is beginning to be reduced while the integration value near Lewisham and Newham has increased significantly. Although there is a tendency for the integration improvement area to shift eastward as a whole, most of them are concentrated on both sides of the Thames River, and the suburbs is less affected than the centre significantly. Some areas not covered by the heat map of stations in the south of the city still show high potential, which shows that the railway network also has an impact on areas far from the station. Under the analysis radius of 20,000m, the position of the Central Activities Zone continues to be weakened. At the same time, the *structure* continues to diverge to the southeast, forming a new gathering point in the outer London area. In addition, a large-scale area with increased integration has emerged in the southeastern part of the city without dense stations.

When focusing on the global research results, an interesting phenomenon emerged (Figure 25 and Figure 26). The city centre, which is also the area with the densest railway stations, is not the place that benefits the most from the railway network as expected. They only accounted for a very small part of the top 5% of the line segments where the integrated value increased (Figure 25). It is not until the top 15% of the difference has been observed that the centre of London regained its status in the *structure*. Surprisingly, the enhancement of integration in the periphery of the city is more obvious, especially in the south of the Thames, where multiple clusters have appeared.

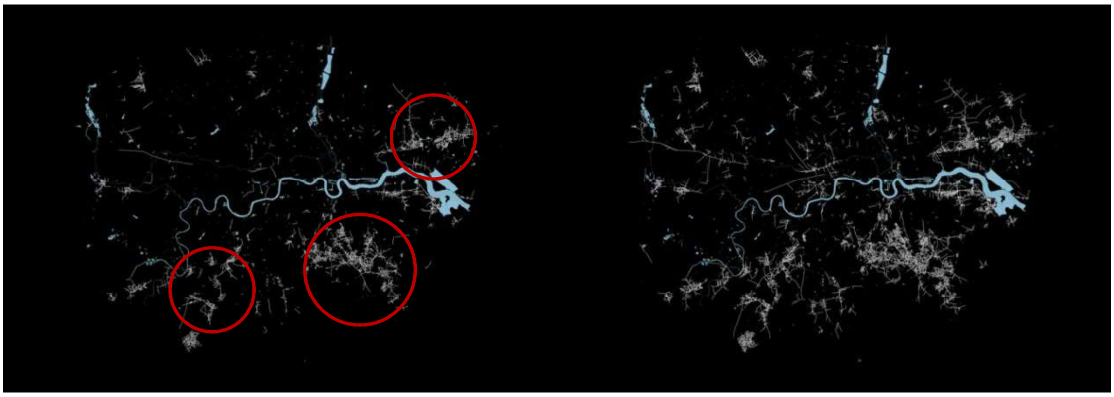

Figure 25: Top 5% of the global integration difference (left)   Top 10% of the global integration difference (right)

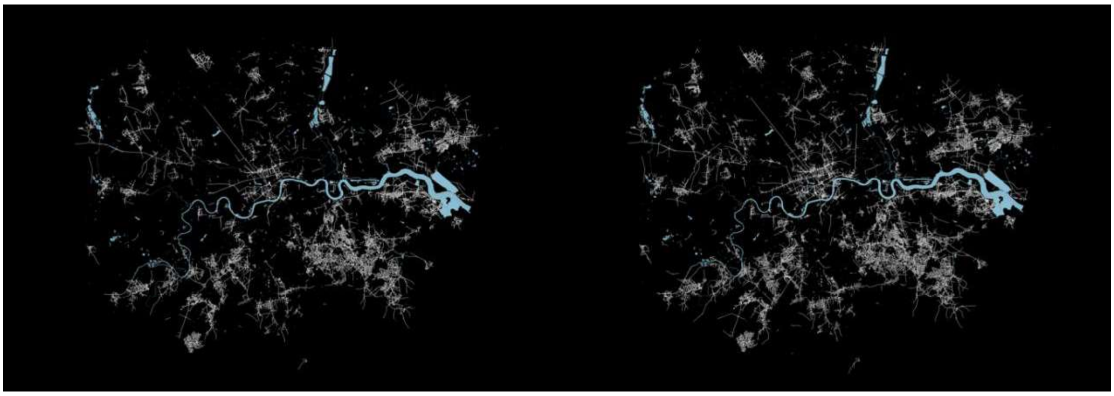

Figure 26: Top 15% of the global integration difference (left)   Top 20% of the global integration difference (right)

4.2 Comparison of PTAL Values and Spatial Accessibility

Figure 27 represents the PTAL map of the Greater London. The dark red indicates areas with the highest PTAL value. Figure 28 is overlay of PTAL map and street-based global integration and Figure 29 depicts overlay of PTAL map and multimodal global integration. As shown in Figure 28 and 29, areas with high spatial accessibility and areas with high transport connectivity have a high degree of overlap, which can be explained by the '*multiplier effect'* of the city. Some areas with advantages or high potentials would usually be developed with higher density and quality during the construction process in order to carry more social and economic activities. And this kind of development has further increased the density of the road network, improved the integration value of the network, and expanded its advantages and potential. Through the development and construction of this kind of cyclical dynamics over a period of time, a structure of spatial accessibility that can be measured at present is finally formed. The similarity between the PTAL map and the integration map also shows that the public transport connectivity is an important reference in the urban development strategy, revealing the important position of the public transport system in the research related to urban planning.

Comparing Figure 28 and 29, in the south of the Thames and part of the outer London, the outputs based on the multimodal network are is better consistent with the PTAL map. Zoom in to the south of the Thames (Figure 30), we can clearly see the difference between multimodal network model and the street-based model.

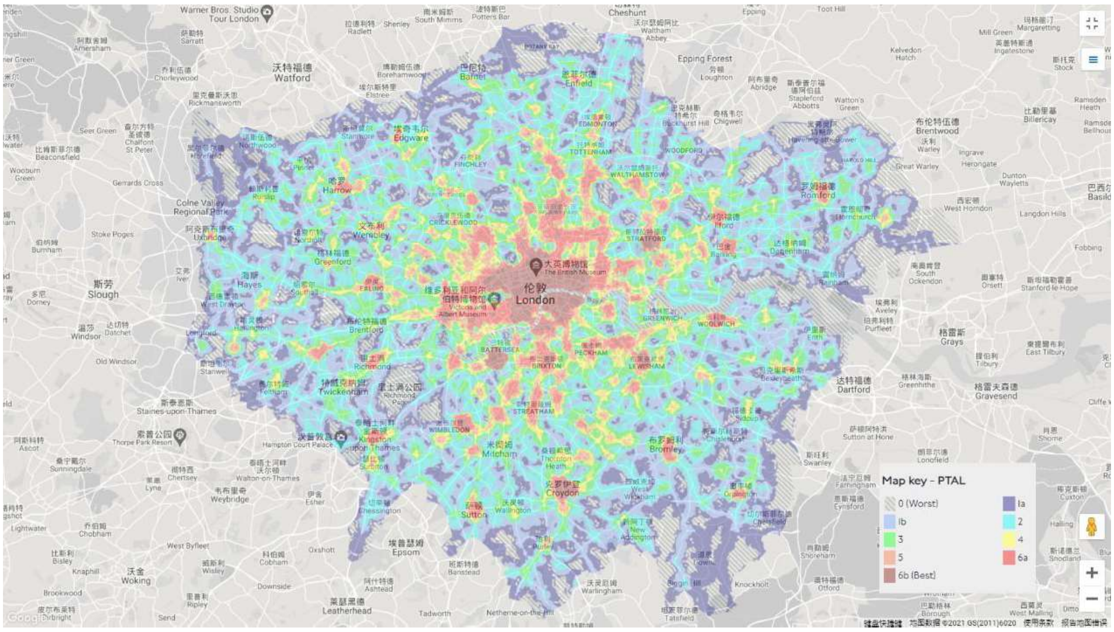

Figure 27: PTAL map of Great London Source: WebCAT planning tool

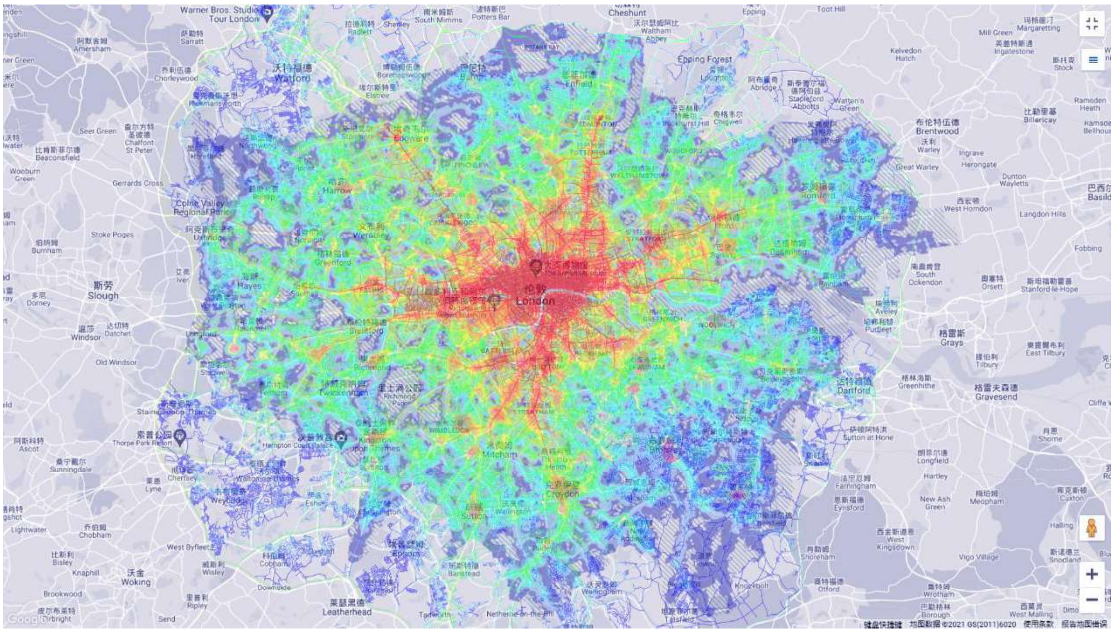

Figure 28: Overlay of PTAL map and street-based global integration

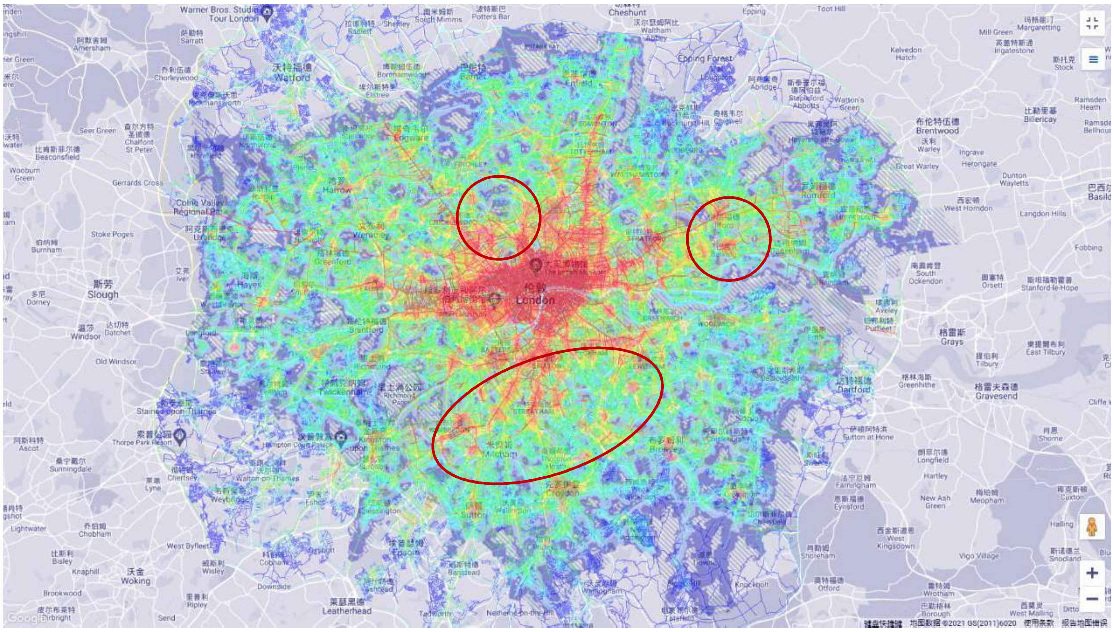

Figure 29: Overlay of PTAL map and multimodal global integration

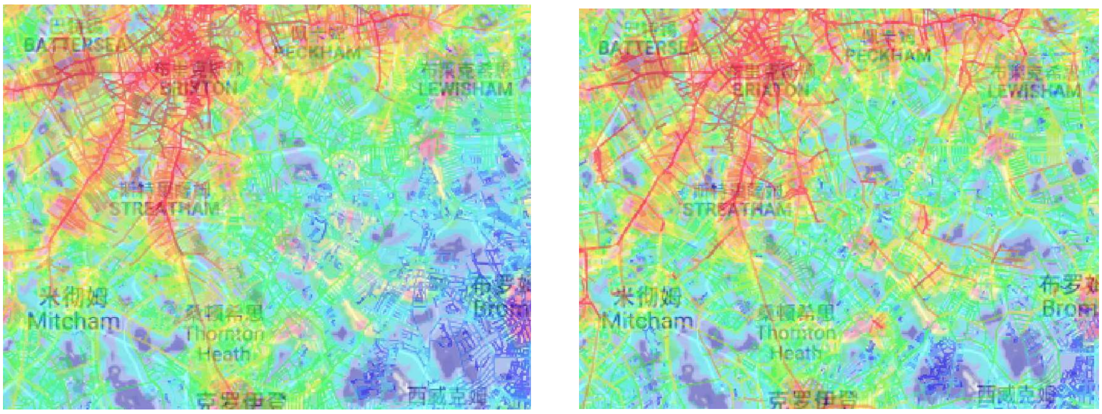

Figure 30: Overlay of PTAL map and street-based (left) and multimodal (right) global integration on the South of the Thames

4.3 Statistical Analysis

Since the color change of segment map is obtained by dividing the line segments into the same interval, it is only describing the distribution of spatial accessibility, rather than precise integration values. In order to understand the details of the integration and choice changes of the two models under different radii, the next work is to quantitatively analyze and research the result data.

Figure 31 respectively show the average normalized integration value (NAIN) and normalized choice value (NACH). As the radius increases, the mean NAIN and mean NACH of the street-based network both decrease slowly. The mean NACH of the multimodal network still drops slightly, but its mean NAIN drops and then rises. Regardless of the radius, the NACH and NAIN of the multimodal network are larger than those of the street-based network because the new model adds more nodes and links to the original model.

Further observe the difference between the two models (Figure 32), the mean NAIN of the two models is very close at 1600m, 3000m and 5000m radius, but it has a gradual increase from 10000m and finally shows an inverse parabolic trend as a whole. As shown in Figure 32, the difference of Mean NACH is almost the same between 1600m-20000m. But there has been a significant improvement in the global scale. After the non-street spatial linking method is taken into consideration, even if the network configuration on the ground level is not changed, it still has a certain degree of benefit to the accessibility of the entire city, which becomes more and more significant as the radius increases.

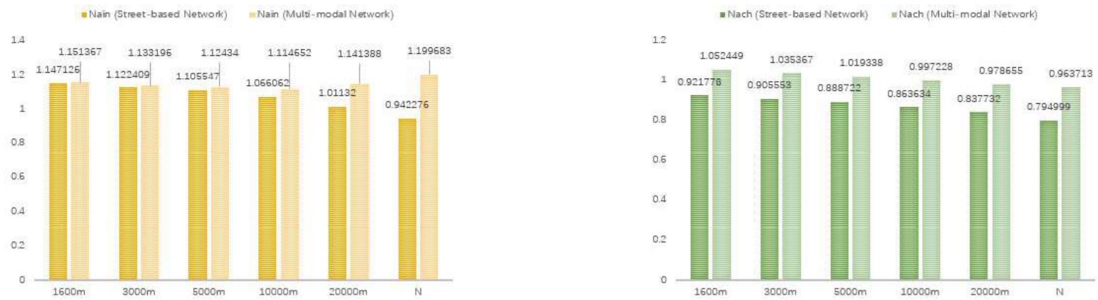

Figure 31: Average NAIN value (left) and Average NACH value (right)

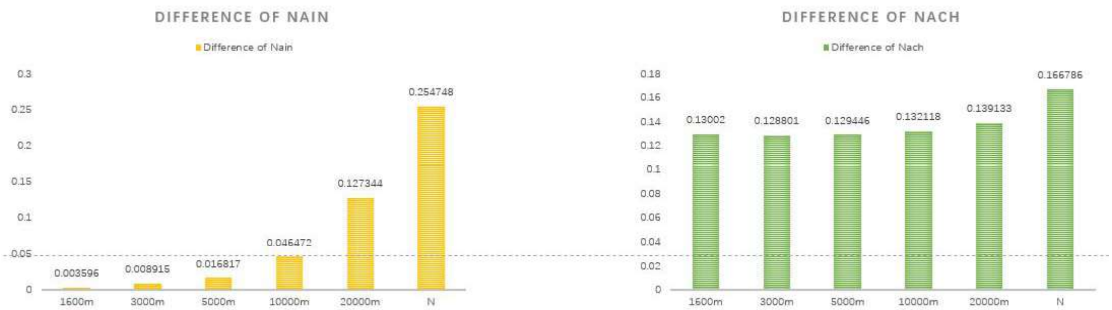

Figure 32: Difference value of NAIN (left) and Difference value of NACH (right)

4.4 Conclusion

This series of results also demonstrates the important impact of the public transportation system on urban development. First of all, in the scale of 1600m to 5000m, it would become a catalyst to promote the vitality of neighboring communities or business circles, and increase the value of land use through higher-density development. Then in the scale of 5000m to 10000m, it would increase the degree of integration of the original centre of the city, which contributes to expand the upper limit of the development capacity of the central area in order to assume more economic, social and leisure functions and provide more jobs. Finally, in the scale of 20000m to global, it can effectively enhance the spatial accessibility of the area outside the geometric centre of the city. The railway system is impactful to a certain extent in areas far away from railway stations on the global scale.

Therefore, railway network is a positive driving force for the development of new urban areas and suburbs. High-quality TOD projects not only stimulate the high-quality development of the local economy and society, but also become an important measures relying on the advantages of the railway network to accelerate the construction of a larger area. It plays different roles under different observation radii and some of which were rarely considered in previous studies. This shows that the multimodal network, as a new model different from the traditional segment map, performs better in demonstrating the structure of the city.

Chapter 5. Space Configuration Analysis around the Station

The previous chapter discussed how the influence of the rail transit system on the overall network properties under weighted conditions varies with the analysis radius. This chapter will further explore how the spatial configuration around the railway stations gets affected by the TOD project.

5.1 Analysis of Station Surroundings

5.1.1 Catchment Analysis of Railway Stations

Figure 33 represents a catchment analysis within a range of 1200m, where the darker red the color is, the closer it is to the station. The density of stations in the centre of the city is significantly higher than that in the periphery, So the city center has better transportation connections. In order to further count the spatial accessibility values of the catchment area within a distance of 0-2000m, the catchment analysis was calculated 10 times with 200m-intervals, and the outputs are demonstrated in Figure 5.2.

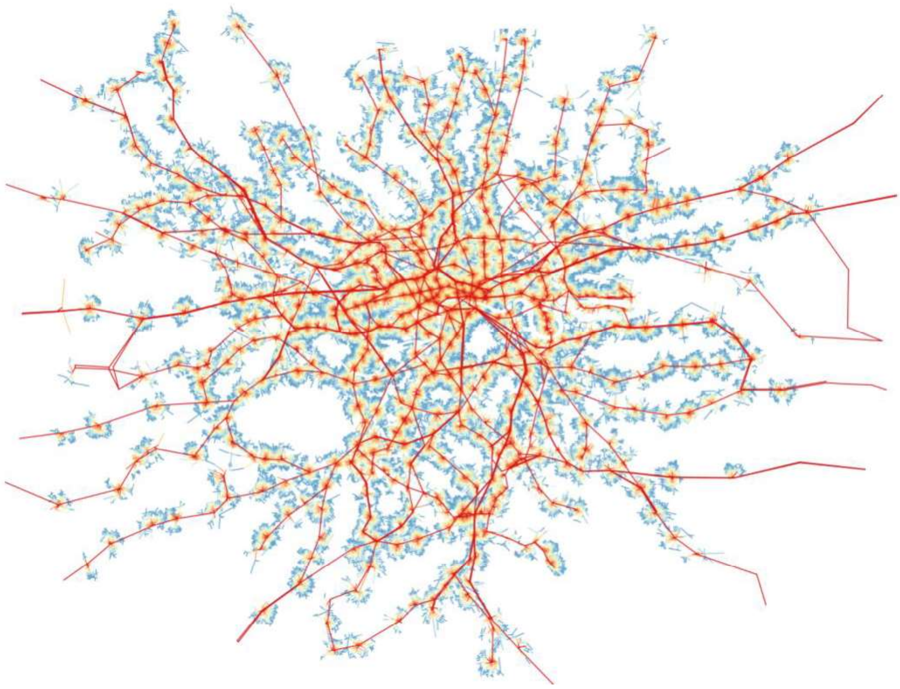

Figure 33: Catchment analysis with radius of 1200 meters

As shown in Figure 34, when the distance to the station increases, the segment length also becomes longer. This means that the farther away from the stations, the sparser the network configuration, while the closer to the station, the denser it is. Although the average segment length in the range of 200-400m is lower than that of 0-200m, their values are very close and do not affect the overall trend of the chart.

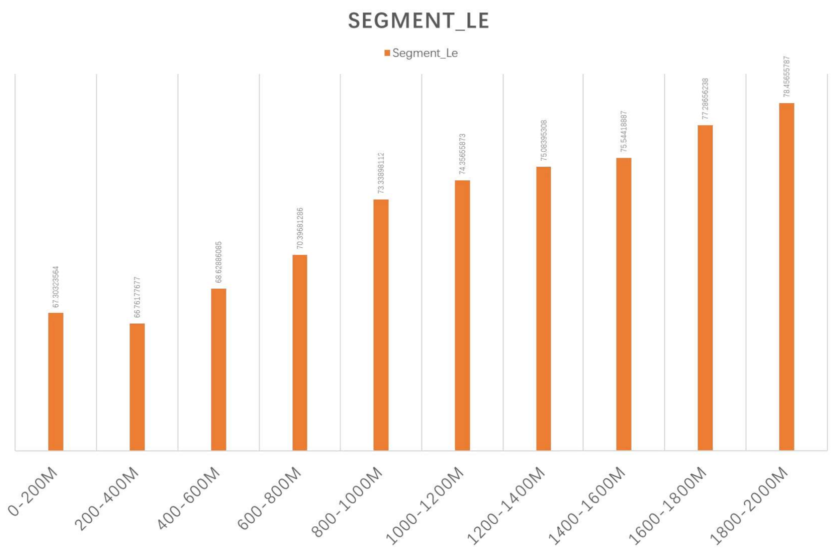

Figure 34: Average segment length of different catchment areas

Figures 35 and 36 demonstrates the average normalized integration of street-based network and multimodal network, and Figure 37 depicts the average difference of NAIN between the two models. Figures 35 and 36 reveal that whether it is a weighted multimodal modal or a traditional street model, the farther from the station, the lower the NAIN. However, in the traditional model, with the spatial syntactic analysis from the local to the global, the mean NAIN gradually decreases. And in the new model, the NAIN increases again starting from 10000m. Figure 37 shows that the change of NAIN near the stations is the largest, which means that the combination of the railway layer and the street layer has the greatest impact on the accessibility of the space configuration close to the stations.

The results reveal that area within 400m from the station has the highest integration and then gradually decreases. The integration values of the line segments with a distance of more than 1200m have less difference and are relatively close. Therefore, when making a decision, the area within 400m is the most concerned about the TOD project.

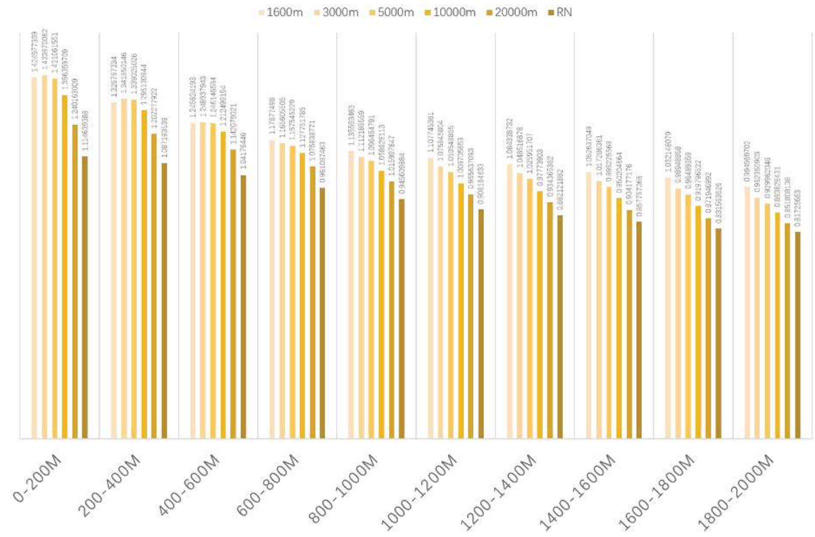

Figure 35: Average normalized integration of street-based network within different catchment areas

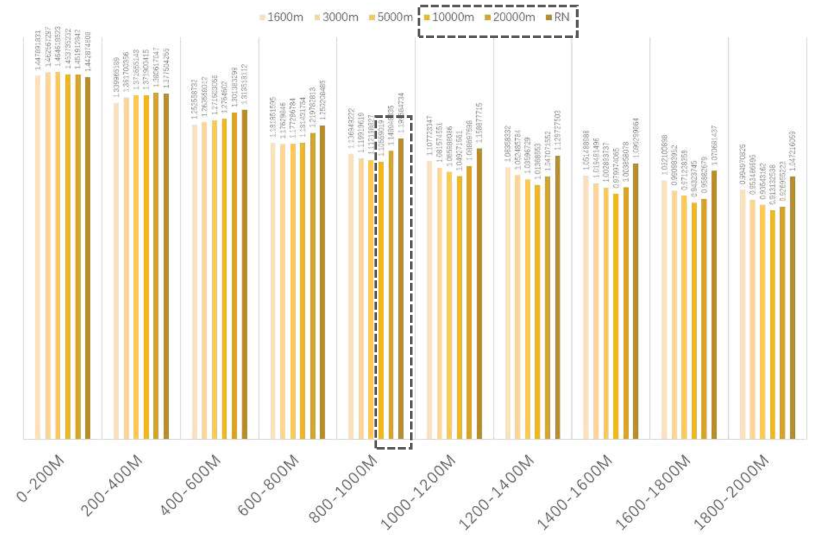

Figure 36: Average normalized integration of street-based network within different catchment areas

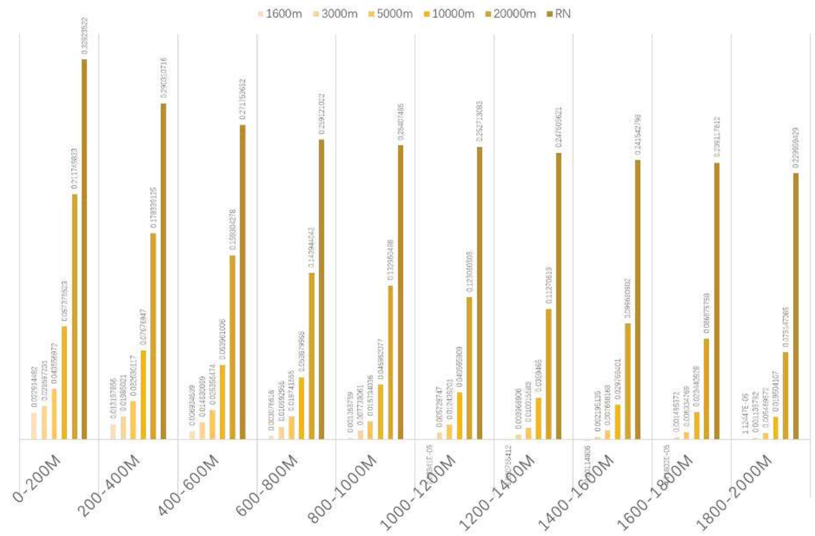

Figure 37: Average normalized integration of street-based network within different catchment areas

Figures 38 to 40 show the corresponding NACH. In the traditional street model, the mean NACH decreases slowly as the distance increases. While in the new multimodal model, this feature is not very obvious. Figure 39 represents that, except for the slightly higher NACH within the 200m catchment area, the average choice value in other catchment areas basically remains at the same level. Different from Figure 37, Figure 40 means that the change of NACH near the station is the smallest. The farther from the station, the greater the difference.

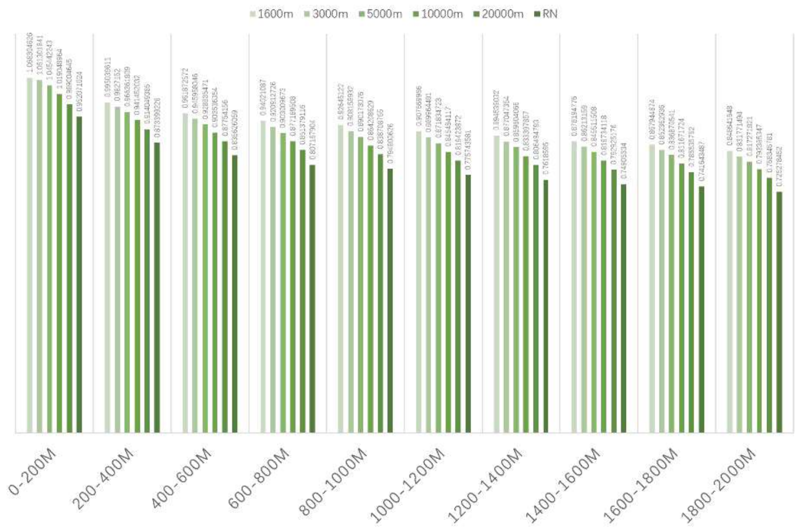

Figure 38: Average normalized choice of street-based network within different catchment areas

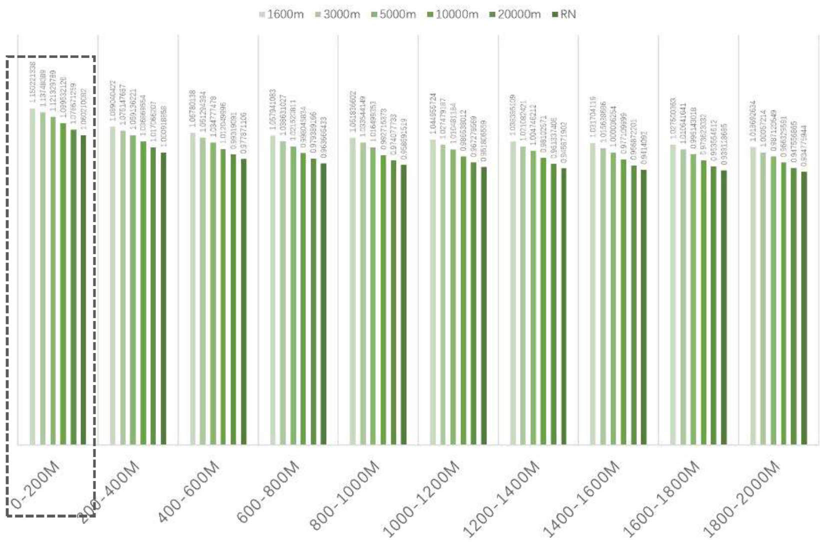

Figure 39: Average normalized choice of multimodal network within different catchment areas

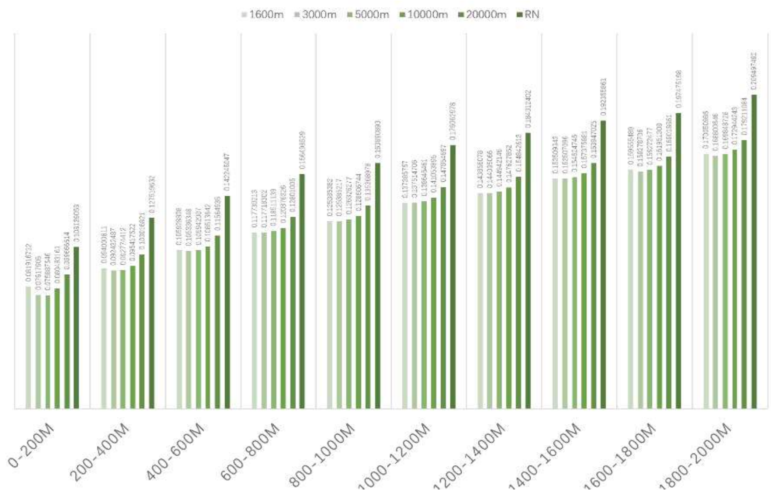

Figure 40: The average difference of the normalized choice between multimodal network and street-based network

A series of R^2 values are obtained from the liner regression analysis of the average accessibility and the average distance from the stations (Table 2). The R^2 of the NAIN and the average distance of the two models has exceeded 0.9, in addition, it is larger than 0.95 in 20000m and RN. However, R^2 of NACH is lower than that of NAIN. And among them, the NACH of the multimodal network is lower than that of the street-based network, which is between 0.7-0.8. The integration value, which is one of the attributes of spatial configuration, has a significant correlation with the distance to the railway stations and the results illustrate the optimizing effect of railways on urban space. Except for the smaller R^2 of NAIN at 1600m, which is 0.671, the difference between two models is above 0.8. This is also in line with our general understanding that the influence of the railway system on the spatial configuration is related to the distance to the stations.

In general, the values of R^2 are both higher, It reveals a strong correlation between changes in urban network configuration and the distribution of railway stations. It also shows the importance of TOD in urban development strategies.

Street-based Network						
R^2	NAIN 1600	NAIN 3000	NAIN 5000	NAIN 10000	NAIN 20000	NAIN RN
Average distance	0.922	0.931	0.938	0.948	0.973	0.975
R^2	NACH 1600	NACH 3000	NACH 5000	NACH 10000	NACH 20000	NACH RN
Average distance	0.905	0.887	0.878	0.876	0.882	0.873
Multimodal Network						
R^2	NAIN 1600	NAIN 3000	NAIN 5000	NAIN 10000	NAIN 20000	NAIN RN
Average distance	0.913	0.928	0.935	0.949	0.976	0.962
R^2	NACH 1600	NACH 3000	NACH 5000	NACH 10000	NACH 20000	NACH RN
Average distance	0.779	0.767	0.748	0.735	0.744	0.740
Difference Map						
R^2	NAIN 1600	NAIN 3000	NAIN 5000	NAIN 10000	NAIN 20000	NAIN RN
Average distance	0.671	0.866	0.887	0.934	0.964	0.806
R^2	NACH 1600	NACH 3000	NACH 5000	NACH 10000	NACH 20000	NACH RN
Average distance	0.991	0.980	0.979	0.983	0.985	0.972

Table 2: Regression analysis of spatial accessibility and the distance from the stations

5.1.2 POI Analysis

POI reflects an important indicator of socio-economic activities and the level of regional development. By comparing the distribution of POI and the coordinates of the stations, it could be observed whether public transportation has a certain attractive effect on POIs.

Figure 41 describes the proportion of POI in different catchment areas. Obviously, most of POIs are located within, nearly 40%. And the number of POIs outside of 1,200m is only 18% of the total. Figure 42 depicts the distribution of all POIs in London and Figure 43 shows the POIs in the catchment areas of 400, 800 and 1200 meters respectively. The results manifest that POIs have a certain agglomeration effect near stations, especially in urban centres. But in Outer London, POI is more evenly distributed.

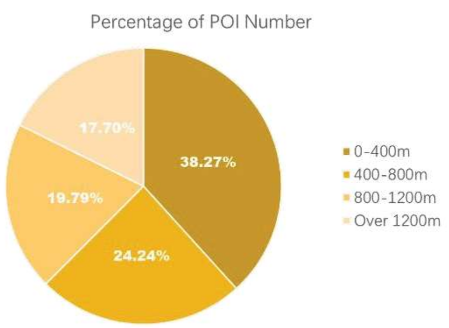

Figure 41: Percentage of POI Number

Figure 42: Distribution of London POIs

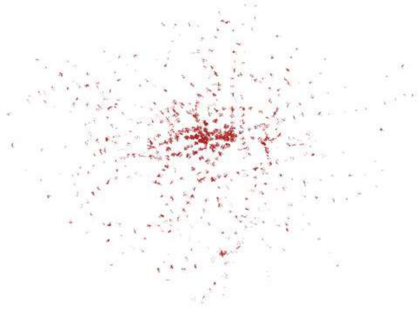

Figure 43.1 POIs within 400m catchment area

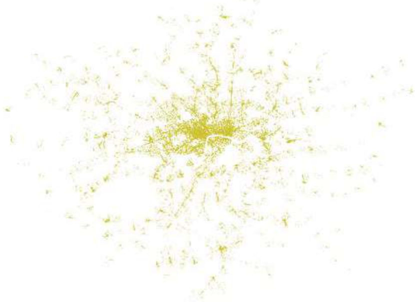

Figure 43.2 POIs within 800m catchment area

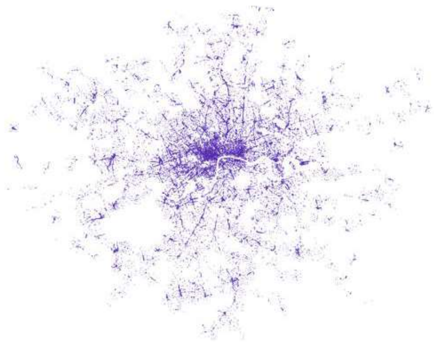

Figure 43.3 POIs within 1200m catchment area

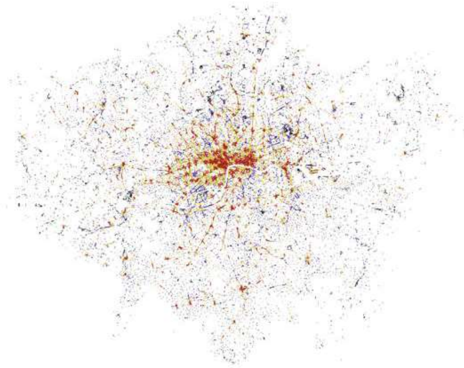

Figure 43.4 Overlay of POIs in different catchment areas

Figure 43: Overlay of POIs in different catchment areas

5.2 Classification and Examples of TOD Projects

In order to better understand the impact of TOD projects on the urban space configuration and functions around the stations, this research divides TOD projects into 6 categories based on location, function, service radius, and user judgment.

	Classification of TOD Projects	Location	Functions and Services	Service Area	Main Users
01	**Commercial Retail Centre**	Old Town or City Centre	High-quality and diversified commercial services	Whole City	Shoppers
02	**CBD Development Area**	Urban Core Area	Core financial services and business office clusters	Whole City	Related practitioners Shoppers
03	**Transport Hub**	——	Distribution and transfer services for personnel and material exchanges	Whole City	Tourists Citizens
04	**Park or Square**	——	Vibrant public spaces	Local Area	Local residents
05	**Large Public Service Facility**	Suburban Town or New Town	Purposeful special functions (such as gymnasiums) and certain commercial office services	Major facilities: Whole City Commercial Services: Local Area	Tourists Local residents Workers
06	**Suburban Town Centre**	Suburban Town or New Town	Retail, commercial and public services that meet regional needs	Suburban Town	Local residents

Table 3: Classification of TOD Projects

Type 01 'Commercial Retail Centre' TOD Projects

This kind of projects is always located in the old city. There are dense buildings, commercial streets and pedestrian-friendly facilities around the stations. Such stations include the Oxford Circus Station, Piccadilly Circus Station, Leicester square Station, Camden Town Station and other core stations in central London.

Detailed Analysis: **Camden Town Station**

Camden Town Station is located in the centre of Camden Borough with a strong commercial atmosphere. It is also one of the 34 key centres in Greater London. Figure 44 represents that streets with high-integrated value spreads radially outwards from the station. And the high-accessibility area also expands with the increase of the analysis radius, the best performance is 10000m. According to Figure 45, the north of the station is more affected by the railway network under the local analysis radius. But when it exceeds 10000m, this inequality gradually disappears. In the global analysis, Camden High St, Parkway and A400 benefit more from the railway network, and they also have high spatial accessibility.

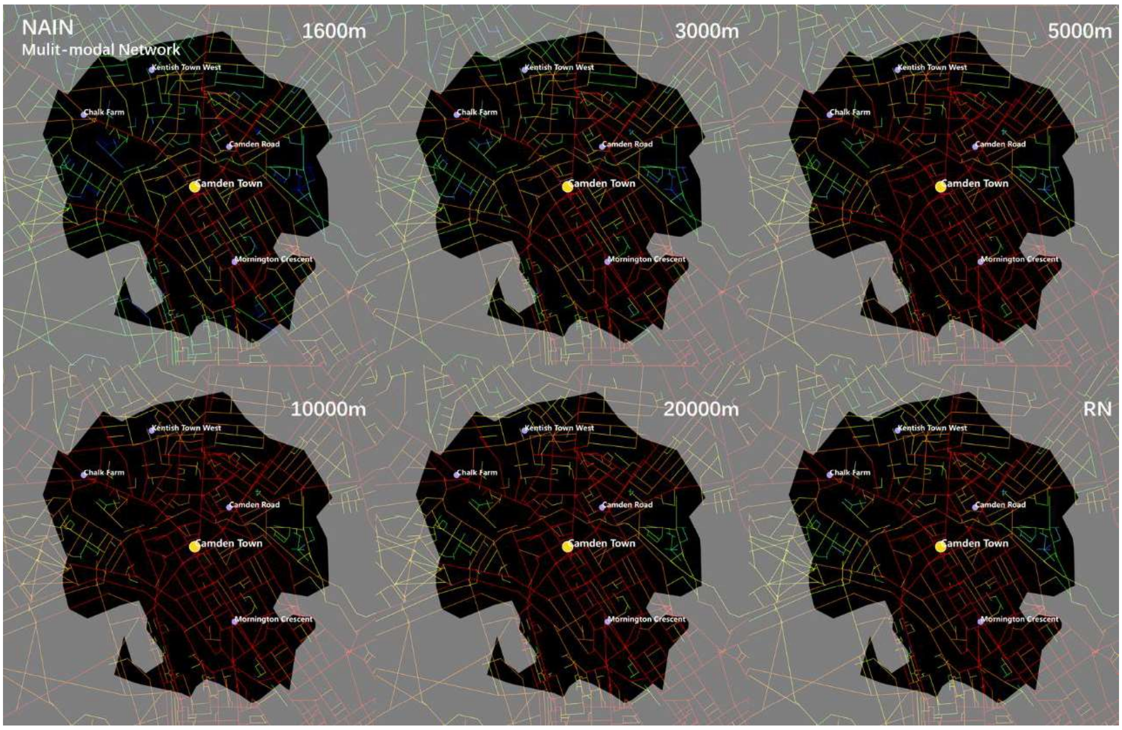

Figure 44: Spatial accessibility of Camden Town Station based on multi-modal network

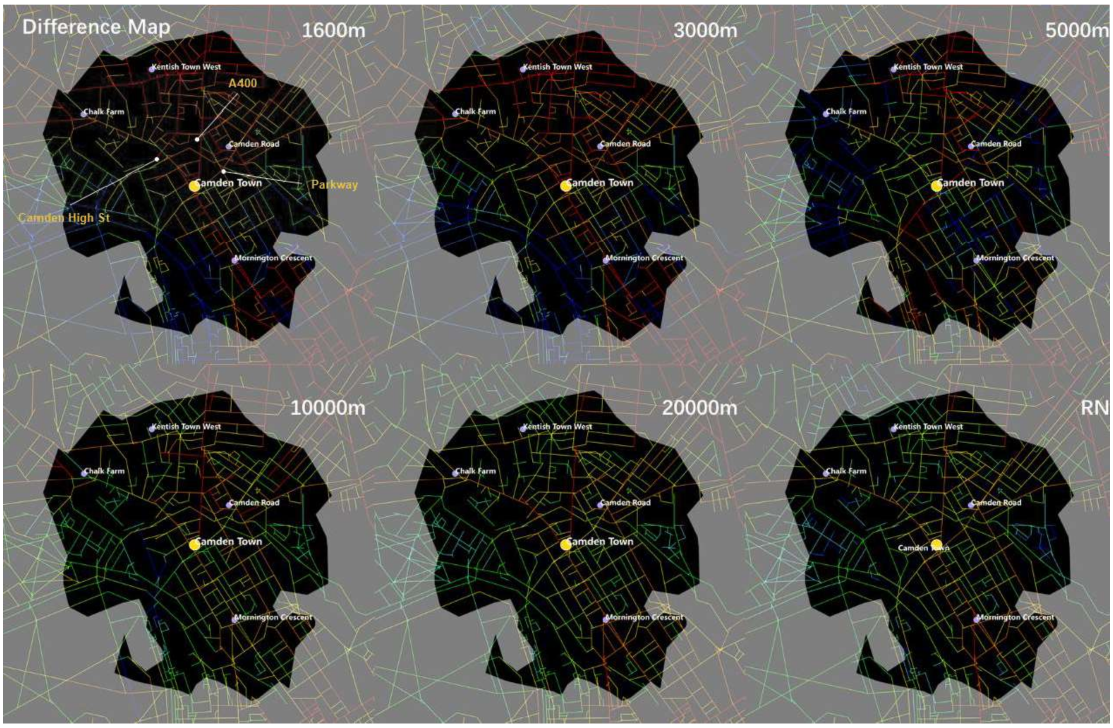

Figure 45: The difference NAIN map of Camden Town Station between multi-modal network and street-based network

There are a lot of retail, business and mixed-use areas around Camden Town Station. In the catchment area within 800 meters from the station, non-residential area occupies nearly 50%. These public facilities mainly spread out along Camden High St, Parkway and A400, where also parts of the line segments that are most affected by rail traffic.

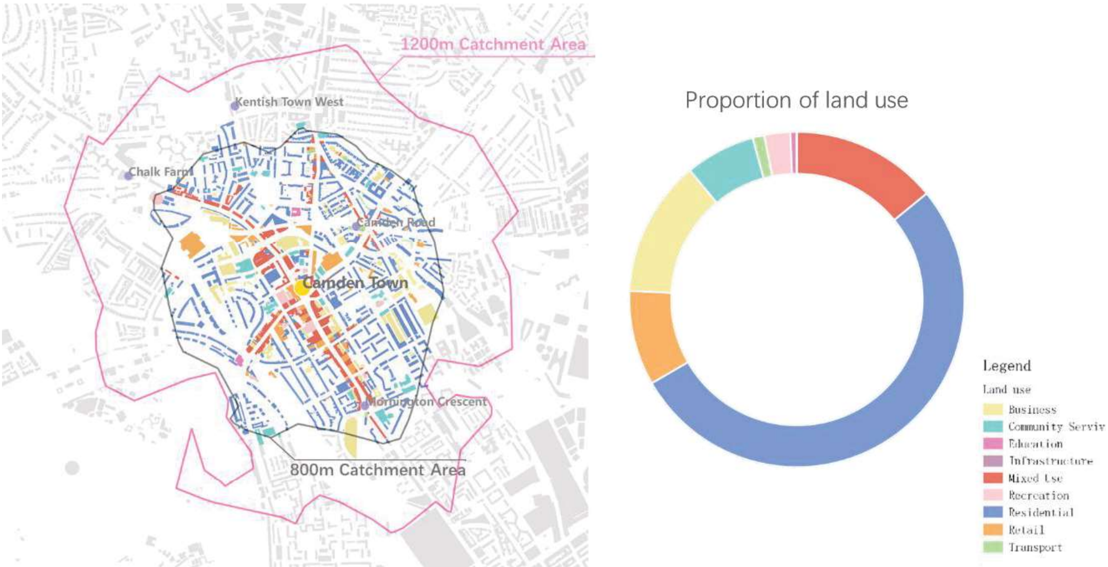

Figure 46: The land use around Camden Town Station

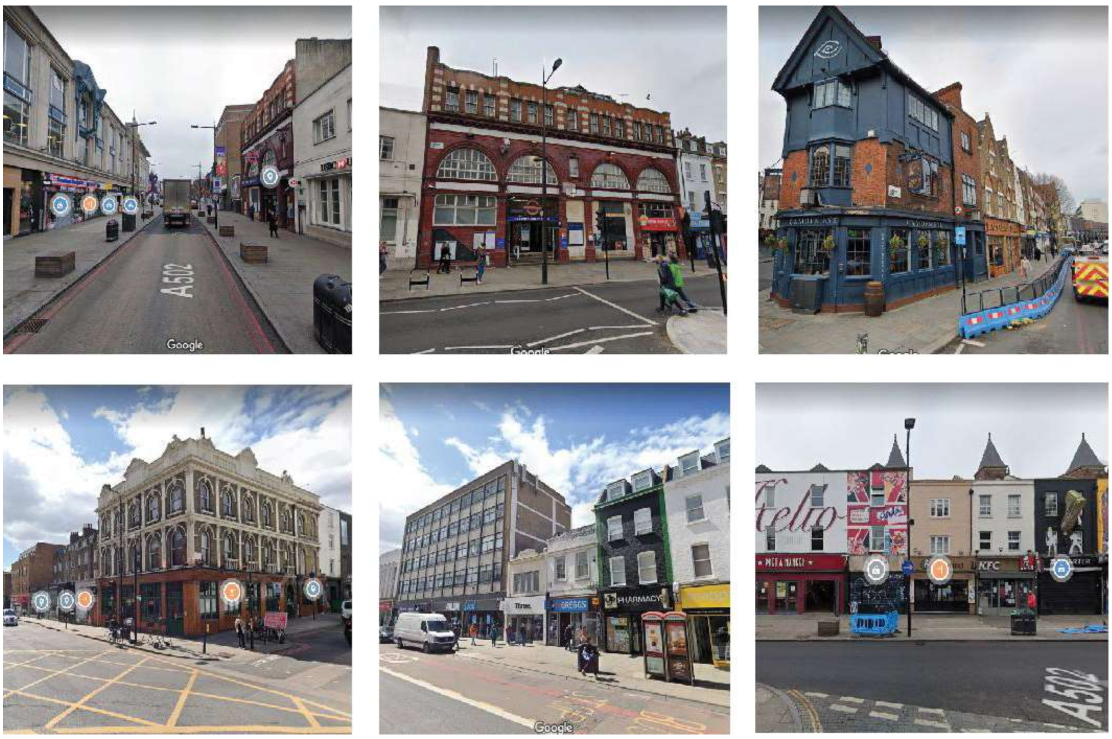

Figure 47: Photographs of the streets around Camden Town Station   Image from Google Street View

Type 02 'CBD Development Area' TOD Projects

This kind of projects is mainly located in places where jobs and capital are concentrated. And mixed development is carried out around the stations to maximize the use of the public transportation capacity. These projects are usually planned with high-density office space or creative park, and supporting multi-functional commercial-office complexes. Such stations include Holborn Station, Canary Wharf, Tottenham Court Road and so on.

Detailed Analysis: **Holborn Station**

Holborn Station is located in the most economically vibrant central area of London with a large number of institutions and service facilities. As shown in Figure 48, this district has a high-density and high-accessibility network layout, but the difference map (Figure 49) demonstrates that, as the analysis radius increases, on the contrary, the influence of the railway network on the spatial configuration around Holborn Station is decreasing. This may be because the site itself is located in the central area of London. According to the conclusion of Chapter 4, the larger the analysis radius, the greater the influence of the railway network on the periphery of the city, so the impact on the centre is weakened.

Figure 50 depicts that in this kind of TOD projects, the proportion of residential is smaller than that of other types. In contrast, business and mixed-use account for a lager proportion. The block scale is small and the road network density is relatively high. A highly developed complex cluster is formed near the station. Google Street View (Figure 51) shows that there are both historical buildings and modern buildings in this area. The facades are neatly arranged along the street, which is an important display window for the image of the city.

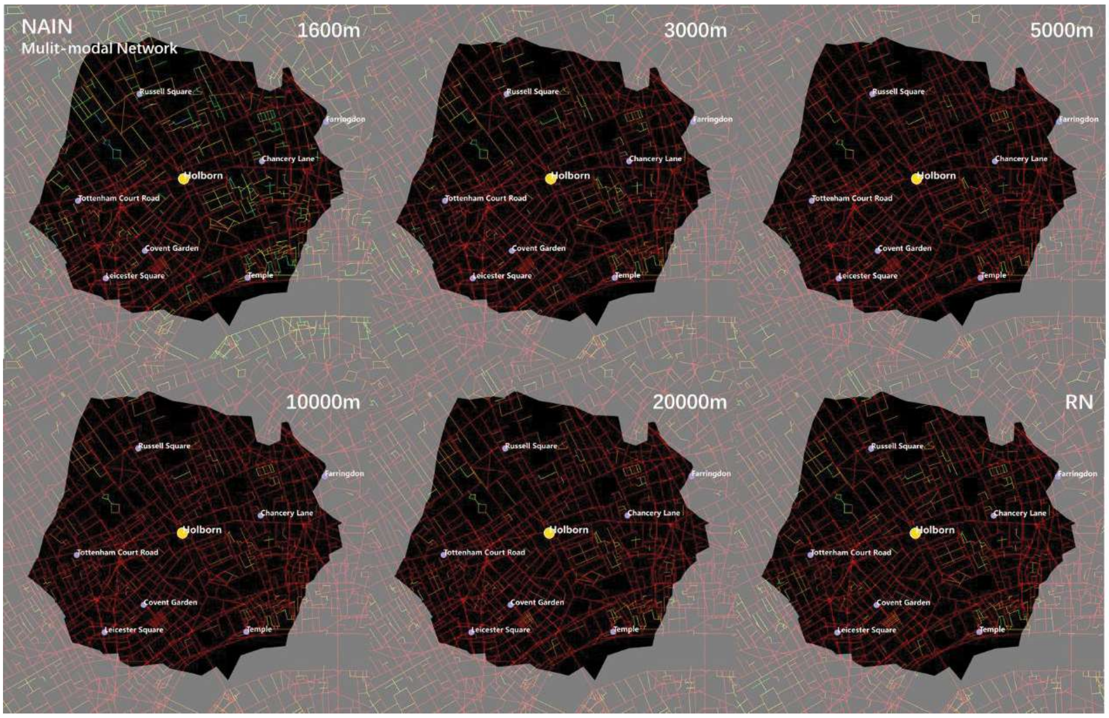

Figure 48: Spatial accessibility of Holborn Station Station based on multi-modal network

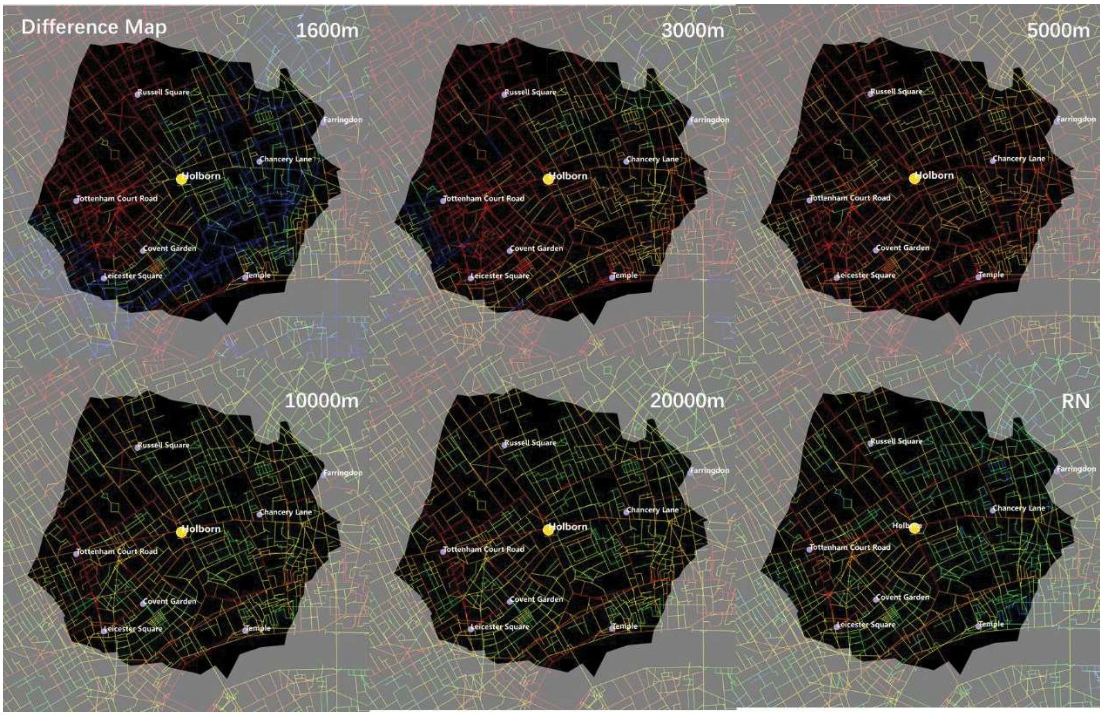

Figure 49: The difference NAIN map of Holborn Station between multi-modal network and street-based network

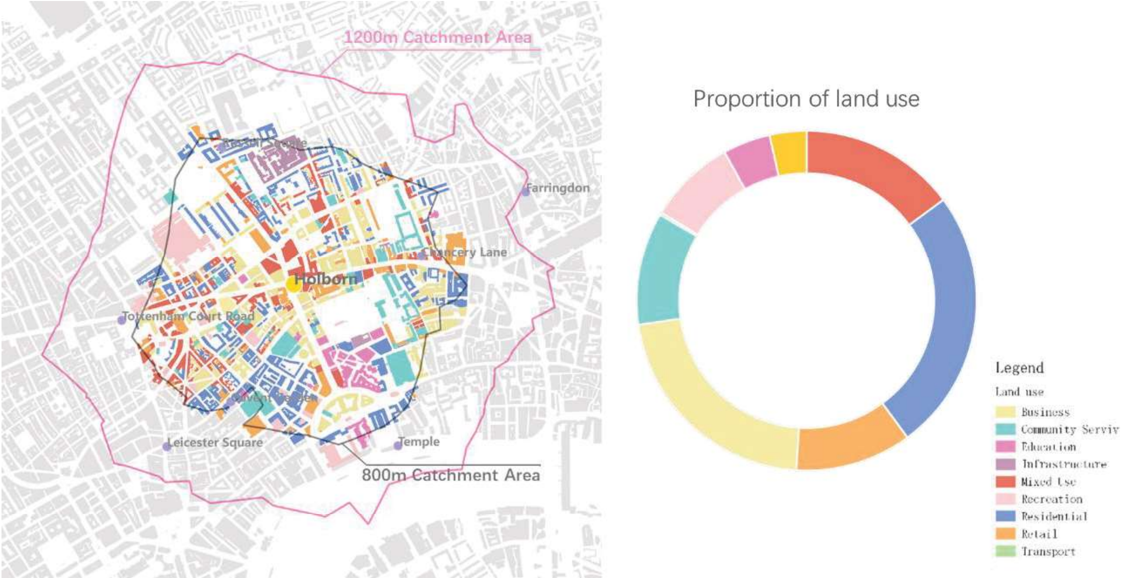

Figure 50: The land use around Holborn Station

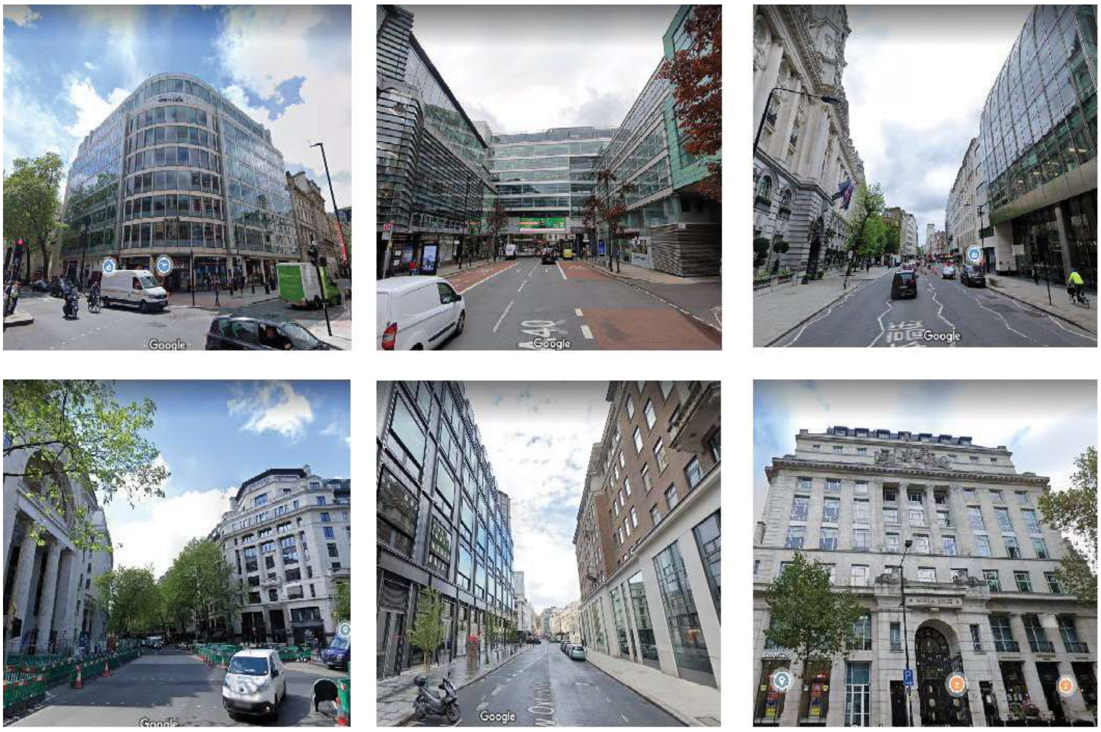

Figure 51: Photographs of the streets around Holborn Station Image from Google Street View

Type 03 'Transport Hub' TOD Projects

There are many train hubs in London and these hubs are intertwined with difference public transportation, which makes them become important nodes connecting the city and the suburbs. Stations like KingCross station, London Paddington station, Euston station, Victoria station, Liverpool Street Station are located in the earlier developed area, such as central London and West London. Stations like Waterloo Station, North Greenwich Station and Stratford Station are located in East London and the south of the Thames without a long history of development. Since the design purpose at the beginning of the transport hubs is usually to meet the traffic demand, the connection with the surrounding commercial facilities and public space is not as close as the previous two types.

Detailed Analysis: **London Victoria station**

Victoria station is one of the important transportation hubs in the Old Town of London. Figure 52 reveals that the spatial accessibility of station surroundings is continuously increasing from local to global. Then when we observe the difference map (Figure 53), we can find that although the influence of the railway on regional accessibility decreases with the expansion of the analysis radius. Under 1600m, 3000m, and 5000m, the accessibility increase in the north of the hub is the most significant, while under 10000m and 20000m, the increase in the south of the hub is the most obvious. A3214 and Ebruy St, which are the streets with high integration value, has been positively affected by the railway network in all cases.

The land use map (Figure 54) and Google Street View (Figure 55) show that the non-residential areas with diverse styles of architecture are mainly distributed along A3214 and Ebruy St. And the advantages brought by the transportation hub have been fully utilized, forming an active cluster mainly composed of retail and commerce near the station. However, the area at a certain distance from the station is still mostly used for residence.

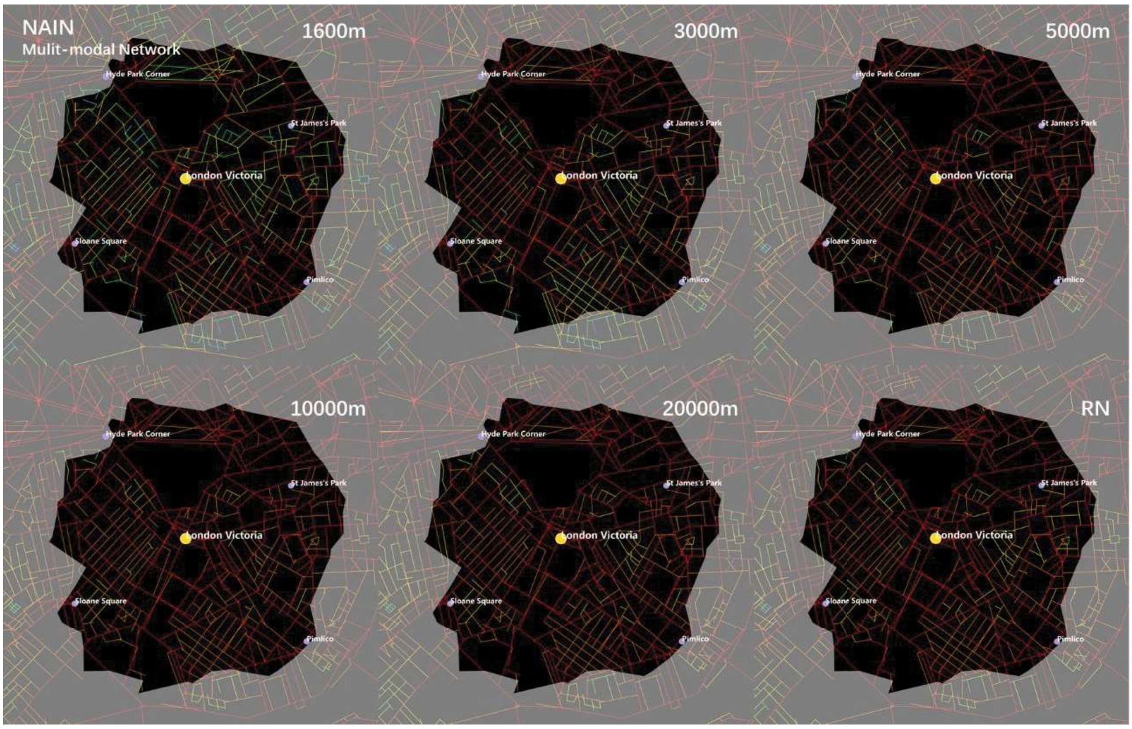

Figure 52: 5.14.1 Spatial accessibility of London Victoria station based on multi-modal network

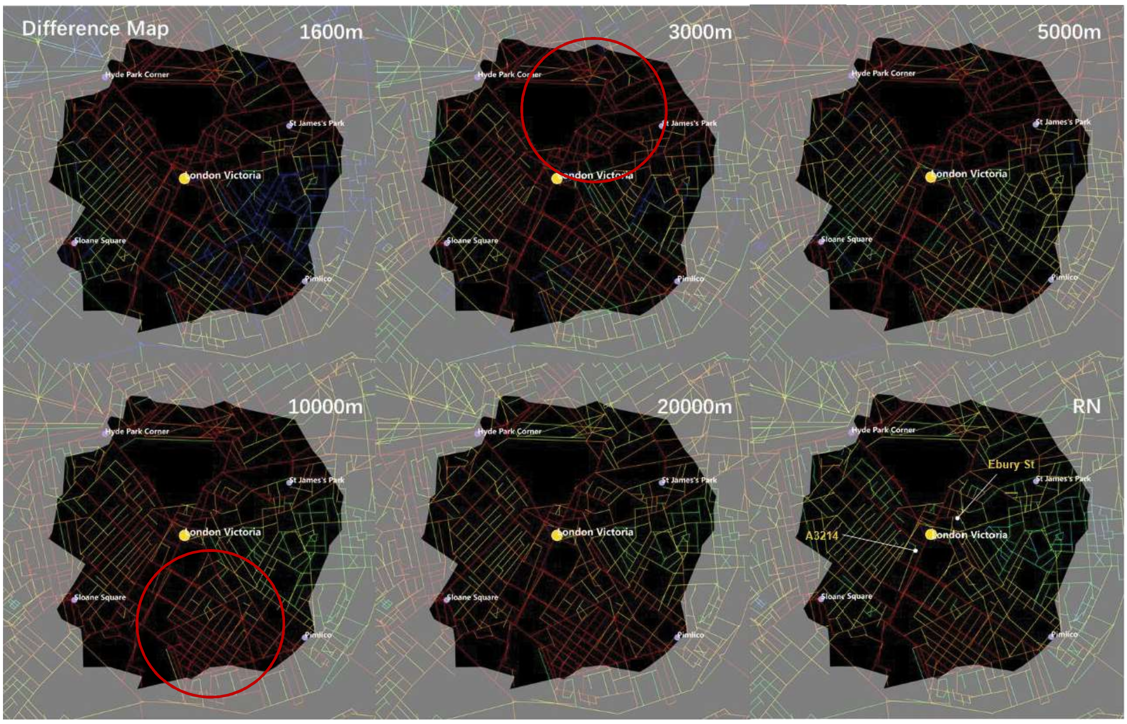

Figure 53: The difference NAIN map of London Victoria station between multi-modal network and street-based network

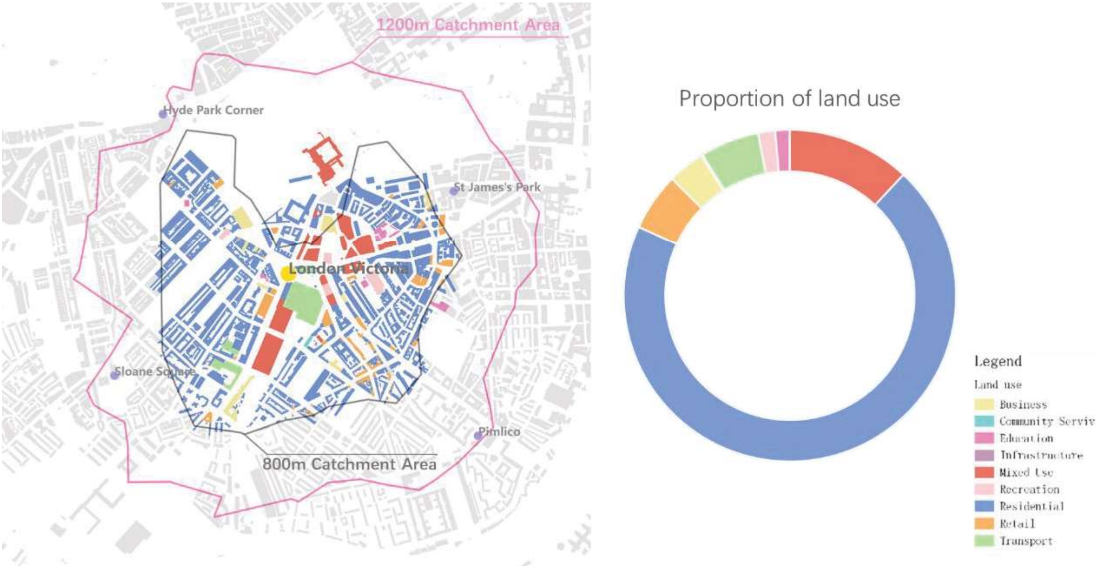

Figure 54: The land use around London Victoria station

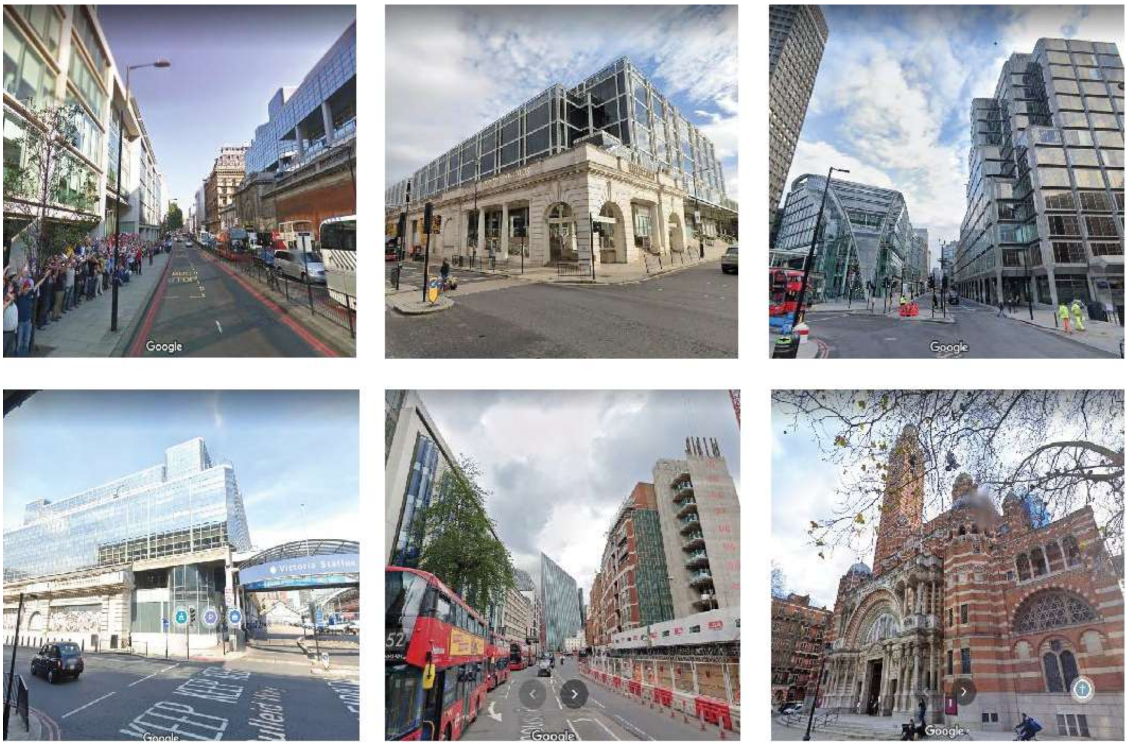

Figure 55: Photographs of the streets around London Victoria station   Image from Google Street View

Type 04 'Park or Square' TOD Projects

Contrary to the high density of the centre, such stations are often located around parks or squares. They create larger public spaces and become attractive places for activities and shopping. High-density areas or high-quality communities are usually concentrated around these parks or squares, forming a composite belt of urban life and landscape. Because this type of projects sometimes is less competitive of those in city centre, it aims to realize the concept of "Park City" and create a beautiful neighboring life become the goals that these projects hope to achieve. Stations such as Elephant and Castle Station, Totteridge and Whetshone Station, Wimbledon Park Station and Turnpike Lane Station are built in this way.

Detailed Analysis: **Turnpike Lane Station**

Turnpike Lane Station, which is adjacent to Ducketts Common Park, forms a wide public activity space at the entrance and exit of the station. As revealed in Figure 56, the streets with high-integrated value (Green Lanes, Westbury Ave, W Green Rd, Turnpike Lane) spread out radially around the station, forming a shape similar to a starfish. And at a radius of 1600m, this structure is clearest. As the radius increases, the integration of these streets decreases slightly. Figure 57 depicts that the spatial accessibility to the west of the station is more benefited by the railway system. In the case of 10,000m, the integration of the station on the west has the greatest degree of improvement. At 20,000m, the east of the station is almost unaffected by the railway network.

As demonstrated in Figure 58 and Figure 59, most of the surrounding areas of the station are residential. Other functions, such as retail, commercial or community services, are mainly distributed linearly along the street. These non-residential areas are more concentrated on both sides of Green Lanes. Although Turnpike Lane has a higher integration value than Green Lanes under the large-scale analysis, the expected service level of such TOD projects is lower than that of stations in the central area. So the analysis radius of less than 3000m can better reflect the local micro economic activity.

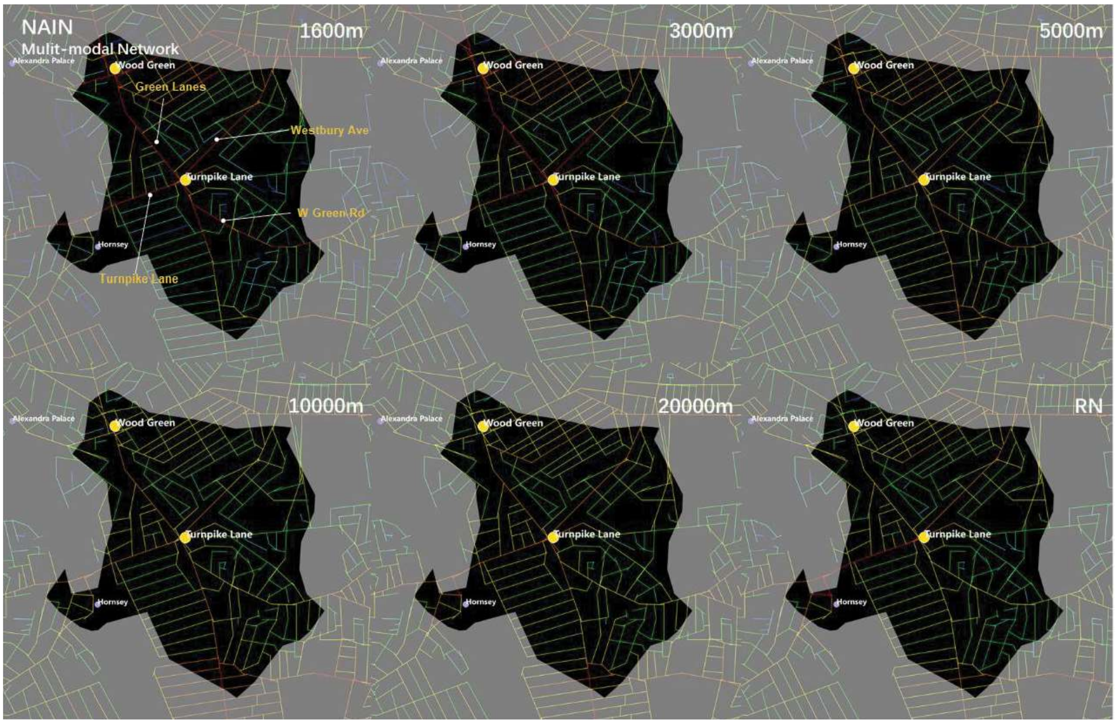

Figure 56: Spatial accessibility of Turnpike Lane Station based on multi-modal network

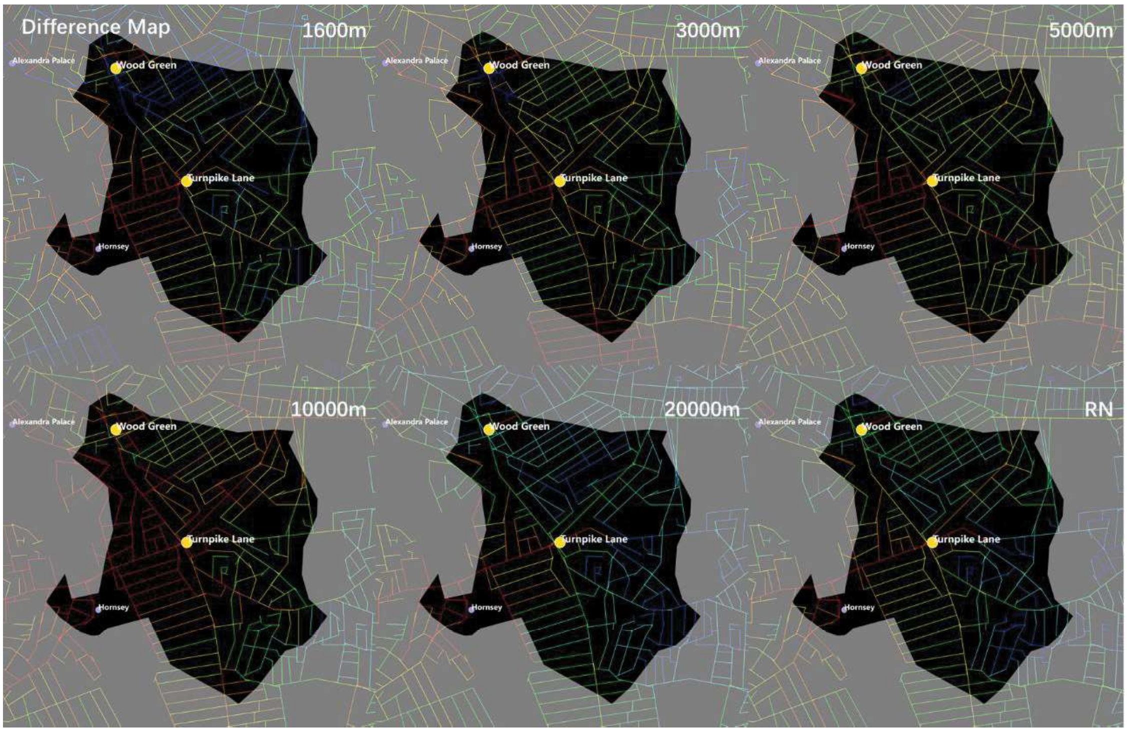

Figure 57: The difference NAIN map of Turnpike Lane Station between multi-modal network and street-based network

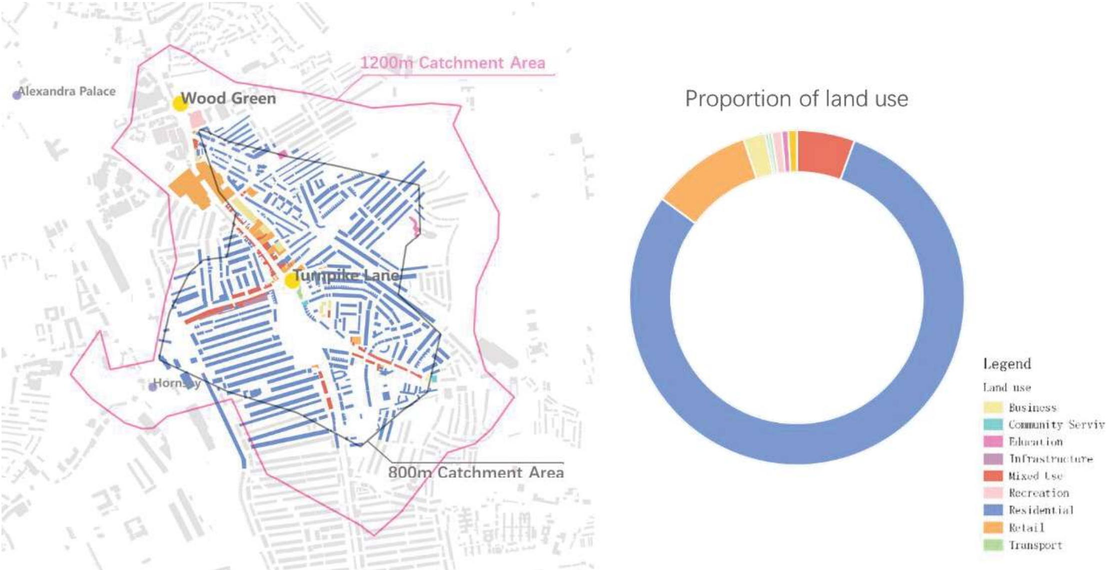

Figure 58: The land use around Turnpike Lane Station

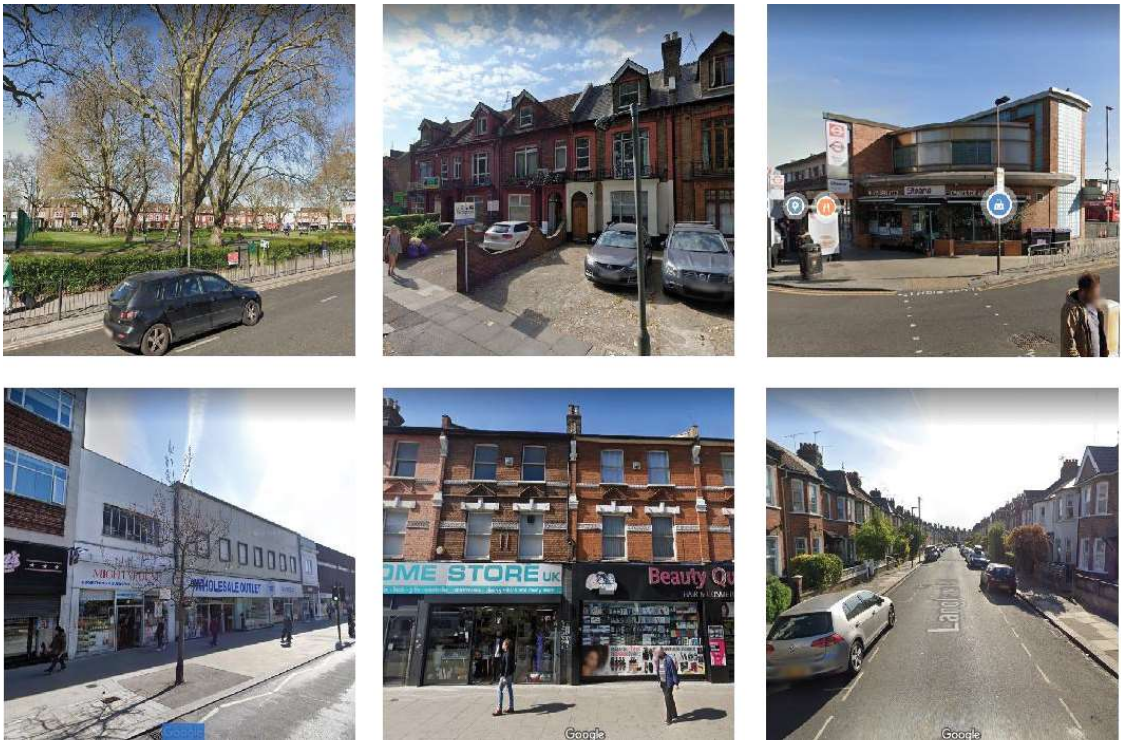

Figure 59: Photographs of the streets around Turnpike Lane Station   Image from Google Street View

Type 05 ‘Large Public Service Facility’ TOD Projects

Large service facilities usually occupy a large area, so they are mostly located in the suburbs or outskirts of the city. Some landmark-type public service facilities usually attract a huge flow of people, and the common development mode utilizes this attraction for commercial development. For example, Wembley Stadium, Tottenham and Drayton Park have built attractors around their stadiums and stations for comprehensive development.

Detailed Analysis: **Wembley Stadium Station**

Wembley Stadium is located in the middle of Brent Borough, which is far from the city centre. It can attract more than 2 million tourists every year, so the subway is used as an important means of transport to there. The development strategy of the project use the stadium as a catalyst to create a new growth pole for commercial services and public services. Observing Figures 60 and 61, there is a certain degree of separation between the north and the south, and the railway has obvious benefits to the spatial accessibility of the northern comprehensive development zone, while the impact on the southern residential area is relatively low.

According to the map (Figure 62) and Google Street View (Figure 63), the south of the station basically only meets the residential needs, and the north of the station is the complex project with high-end apartments, commercial complexes, star hotels and office buildings around the Wembley Stadium. A very obvious comprehensive public service cluster centered on the gymnasium has been formed.

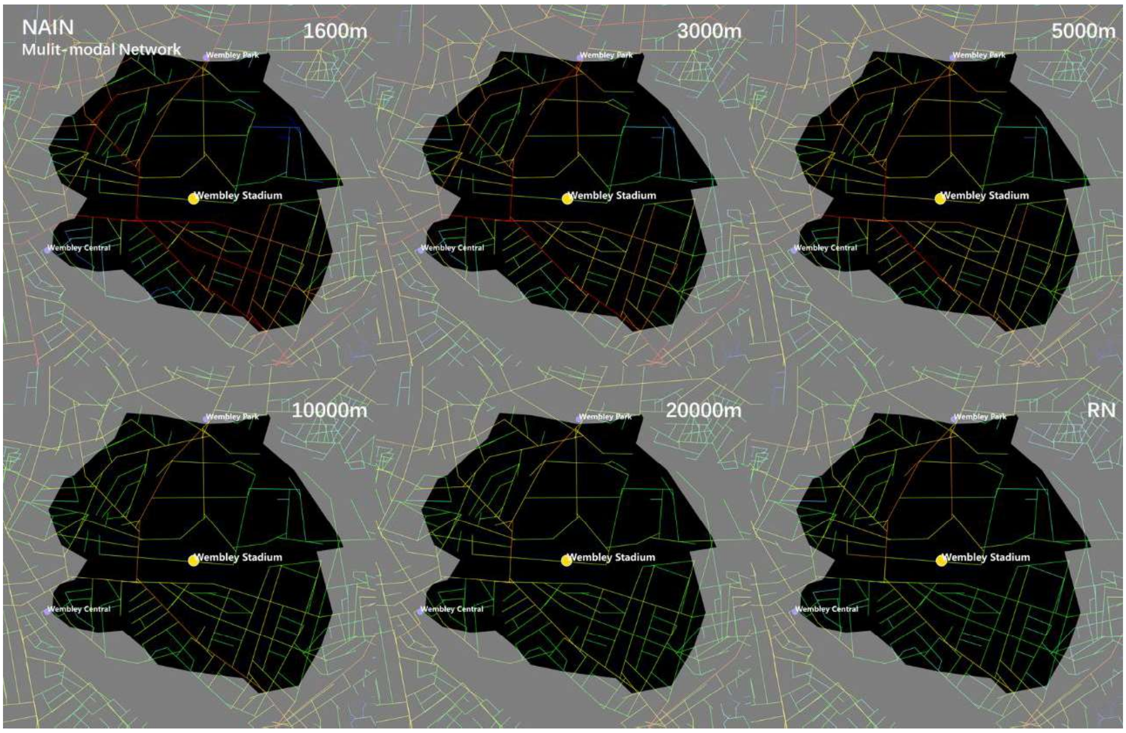

Figure 60: Spatial accessibility of Wembley Stadium Station based on multi-modal network

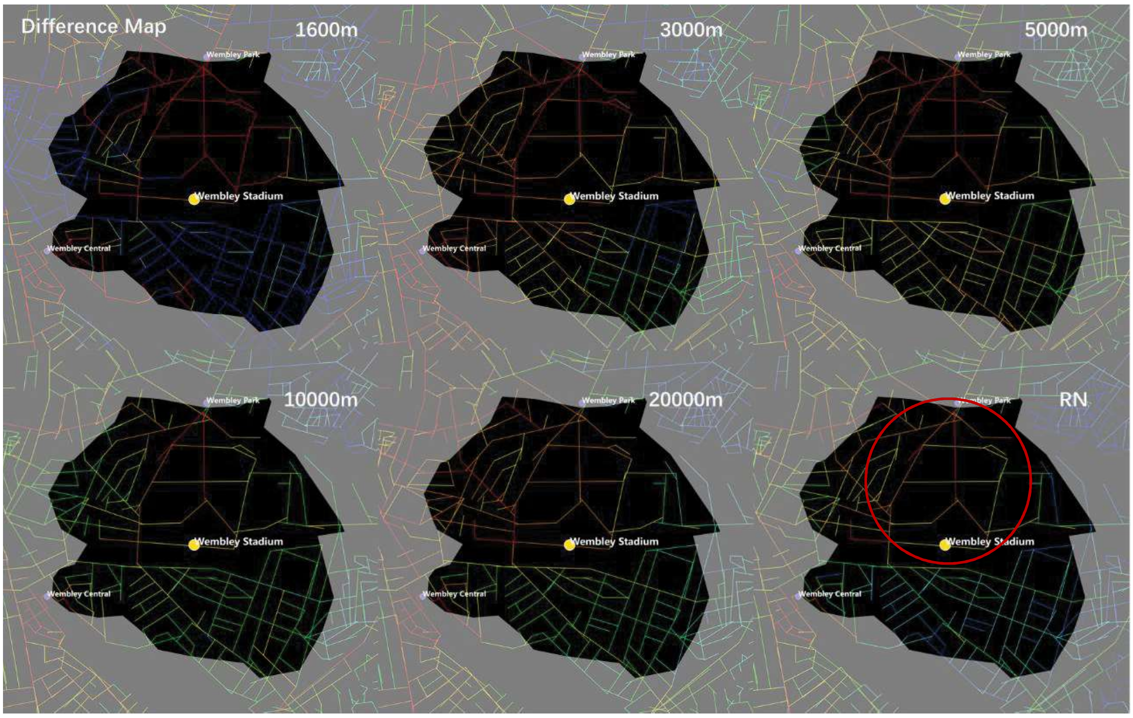

Figure 61: The difference NAIN map of Wembley Stadium Station between multi-modal network and street-based network

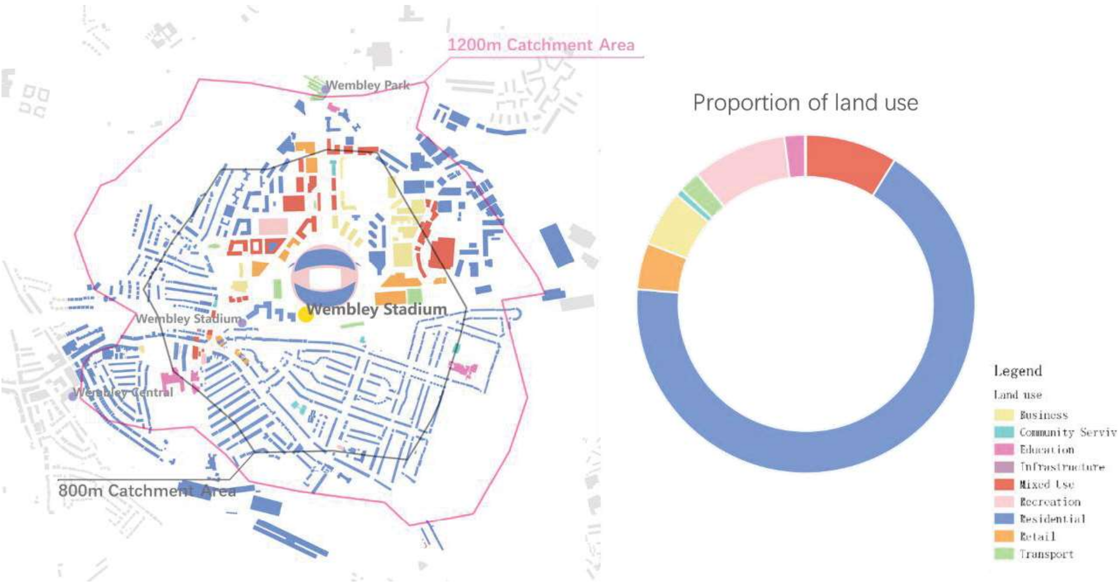

Figure 62: The land use around Wembley Stadium Statio

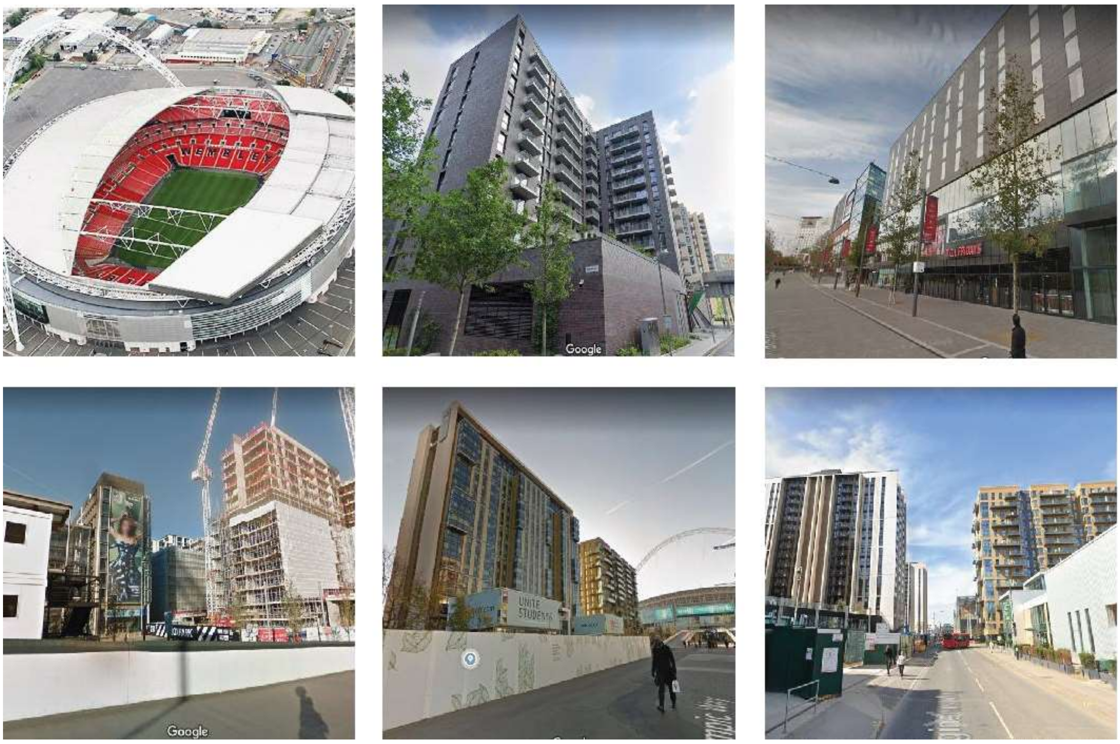

Figure 63: Photographs of the streets around Wembley Stadium Statio Image from Google Street View

Type 06 'Suburban Town Centre' TOD Projects

The suburban town centres are always built around the stations and this kind of projects is designed to provide various public services and commercial support to the suburban areas nearby. So these centres are often arranged with complex commercial, residential communities, office services and other places. Such stations include Cricklewood Station, Wood Green Station and Hendon Central Station and so on.

Detailed Analysis: **Wood Green Station**

As illustrated in figure 64, streets with high-integrated value (A105, A109 and Lordship Ln) spread out radially around the station. Under the radius of 1600m and 3000m, the spatial accessibility near the station is higher. But as the analysis radius increases, the overall accessibility of the area decreases. Figure 65 demonstrates that, on the whole, the west of the station is benefited by the railway network more, and the railway promotes the area most at 10,000m. In the case of 1600m, 20000m and RN, the increase of integration is less, indicating that the public transportation network has not caused too significant impact on the area.

The land use map (Figure 66) shows that at the intersection of the main street, a cluster of commercial activities is formed, and the commercial atmosphere along the street is strong. Since the main service area is the suburban town, there is a certain amount of office space and public service facilities along the street. Google Street View (Figure 67) depicts that the businesses near Wood Green Station are higher-end than those around Turnpike Lane Station, which is mainly residential services.

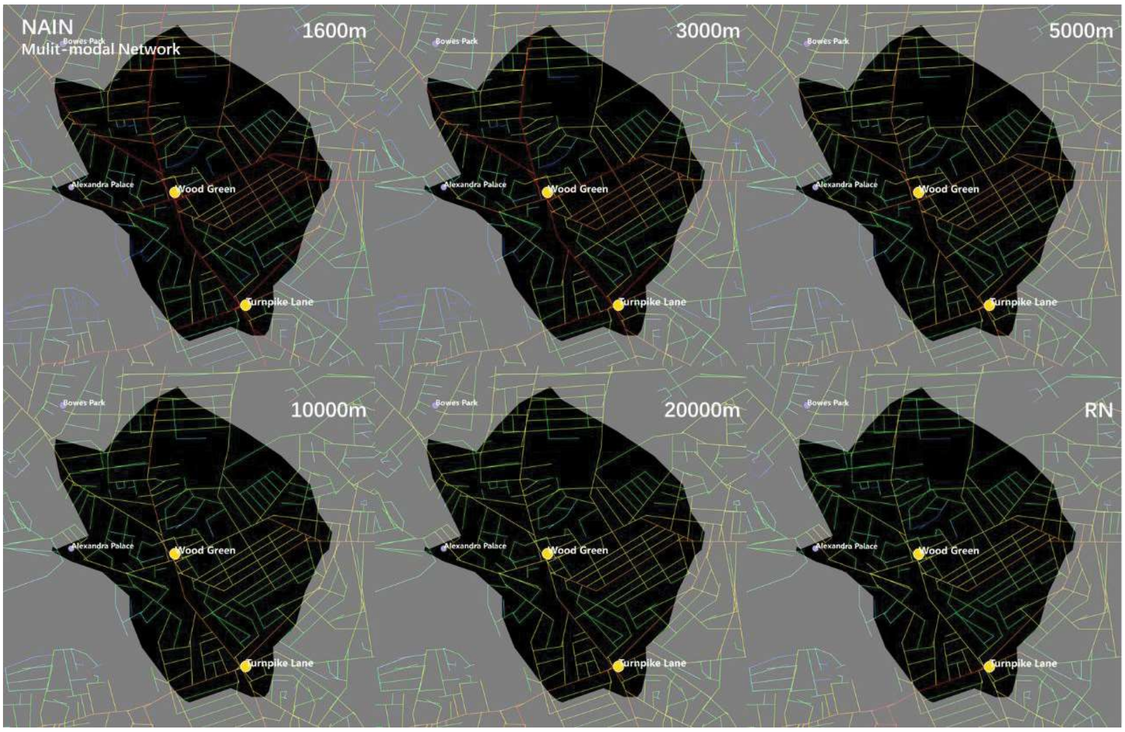

Figure 64: Spatial accessibility of Wood Green Station based on multi-modal network

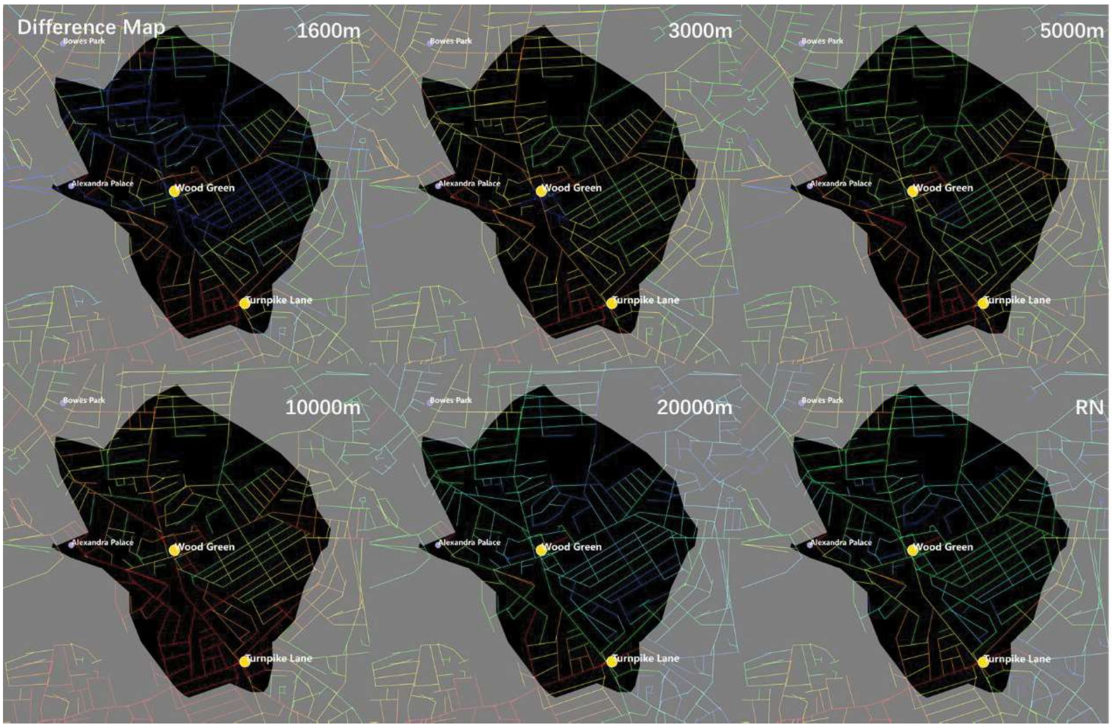

Figure 65: The difference NAIN map of Wood Green Station between multi-modal network and street-based network

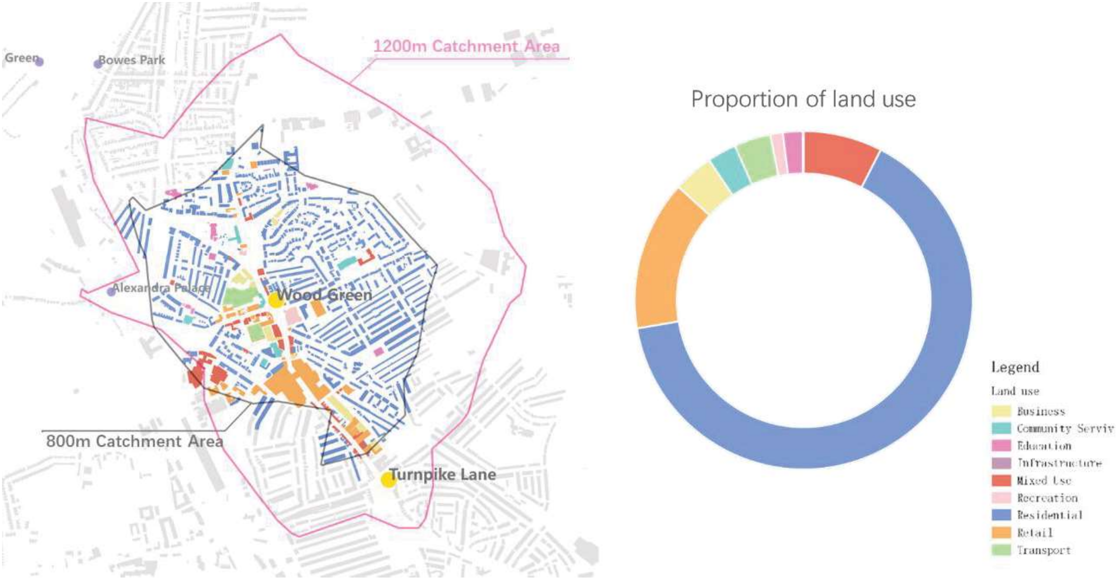

Figure 66: The land use around Wood Green Station

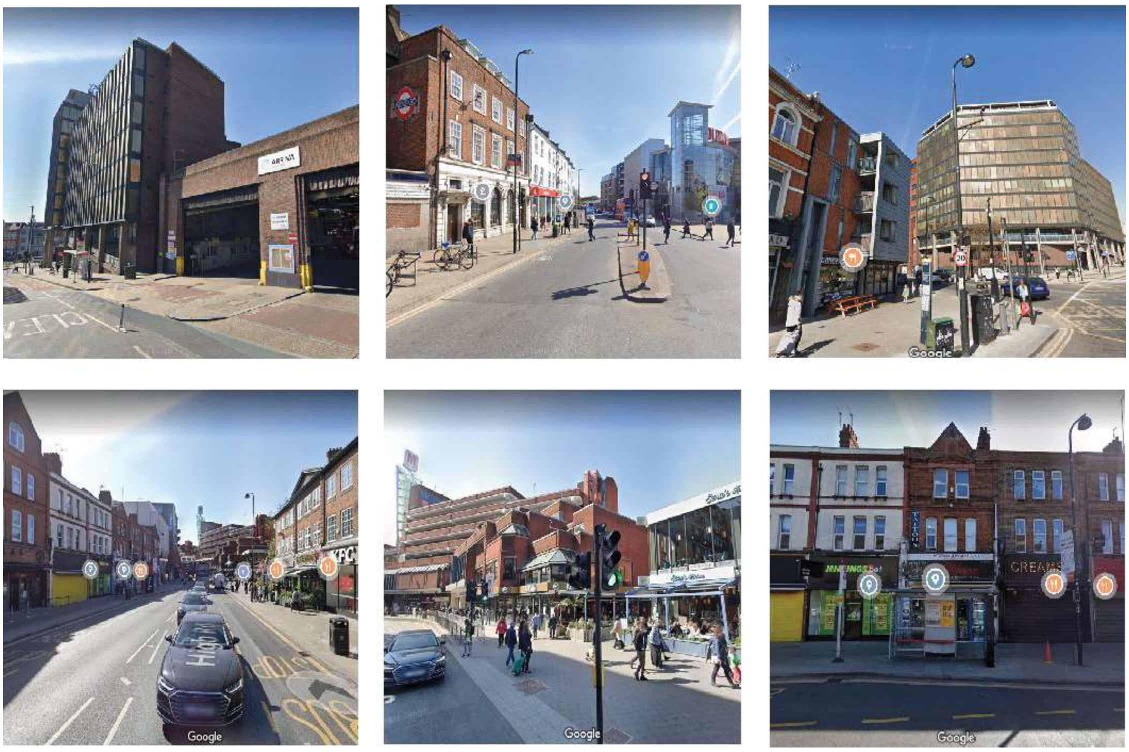

Figure 67: Photographs of the streets around Wood Green Station   Image from Google Street View

Some similar TOD development principles run through these projects, but they also retain their particularity and differentiation that vary from place to place. It is precisely because of the differentiation of these places that many stations in London have their own unique charm. And It also allows many projects to find their own positioning to better serve the citizens and the city.

5.3 Overview

On the whole, the public transportation system plays a significant role in promoting the accessibility of the spatial configuration around the stations. The closer to the station, the higher the density and accessibility of the urban network configuration. Meanwhile, the distribution of non-residential area is similar to the structure of the different map between two models, which indicates that public services are more likely to be arranged in areas that are more influenced by the railway network. However, in the detailed analysis, different stations are affected by the public transportation system differently. So the evaluation of TOD projects needs to be combined with specific local conditions.

Chapter 6. Discussion

The first part is to construct a multimodal network and test its closeness and betweenness in Depthmap. Quantitatively analyze the impact of the railway network on urban space. By comparing the multimodal network and the traditional street-based network from the local to the global, this study analyzes the influence of the public transportation system on the accessibility of the street network configuration on different scales. The comparison of visualized maps and the calculation of statistical data show that after the non-street spatial linking method is taken into consideration, even if the network configuration on the ground level is not changed, it still has a certain degree of benefit to the accessibility of the entire city, which becomes more and more significant as the radius increases.

The second part is to analyze the change trend of the spatial configuration and spatial accessibility around the stations, and discuss the stimulus effect of TOD on urban development in different categories. The results demonstrate that the average spatial accessibility of the urban network configuration within the catchment area has a significant correlation with the distance to the stations. The closer to the station, the higher the line segment density and integration value. It should be noted that due to the complexity and diversity of cities, there may be huge differences between TOD projects, and their assessment and construction need to be combined with specific conditions. But on the whole, high-developed areas are more likely to be formed near streets that are more affected by the railway network.

There are still some limitations in this study. First of all, the multimodal network in this paper only contains the railway layer. Future research could continue to add other travel modes such as the bus layer and bicycle layer to the new model. Secondly, as the third chapter mentioned that the model was simplified for the operability and comprehensibility of the analysis, which caused a certain degree of deviation in the results. Finally, the correlation analysis between the socio-economic data and the railway system in this study is still relatively rudimentary, and more research could be done in the next work.

Most TOD-related policies are usually formulated without theoretical guidance, and decision makers mainly use experience and intuition to make guiding suggestions for related developments. However, spatial syntax provides a quantitative perspective for understanding urban phenomena. It can be analyzed on a scale that is difficult to capture intuitively, so that decision makers can provide more targeted policy recommendations for the future development.

Policy Recommendation 01 Maximize the value of land within 400m from the stations

The most valuable area of TOD project is within 400m from the stations, and the impactful factors of stations in areas beyond 1200m have been relatively small.

Policy Recommendation 02 Strengthen railway network coverage in suburbs or new cities

The accessibility of the railway network to the suburbs, especially South London, has a significant improvement in the large-scale study.

Policy Recommendation 03 Diversify TOD projects under different positioning

Due to distinctions in location, function, and service radius, TOD projects have different focuses. Formulating standard refinement indicators could be helpful for decision-making.

Chapter 7. Conclusion

In summary, the multimodal network combined with public transportation layer provides another perspective for studying urban spatial properties. The results reveal that the rail network has an important optimization effect on urban development in at least two dimensions. Firstly, in terms of the overall morphological composition of the city and the nature movement within the city, this study tested the influence of the public transportation system on the accessibility of the street network configuration on different scales. Especially in the context of global analysis, it can effectively promote the spatial accessibility of the area that occupies the outside in the geometric structure of the city. This is a positive driving force for the development of new urban areas and suburbs. Secondly, according to the analysis of TOD projects that combine specific urban functional spaces and economic activities, the railway network is beneficial to the space attributes and functional layout around the stations. It is worth noting that for different types of TOD projects, the manifestation of the effect is not the same. It shows particularity and differentiation. Decision-making about TOD is also more complicated because of its particularity and differentiation.

Therefore, high-quality TOD projects not only stimulate the high-quality development of the local economy and society, but also become an important means which relies on the advantages of the railway network to accelerate the construction of a larger area. It plays different roles under different observation radii and some of which were rarely considered in previous studies. This shows that the multimodal network, as a new model different from the traditional segment map, performs better in demonstrating the structure of the city.

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