Classifying stations by Place Value

In order to identify the extent to which a transit station can function as a transit-oriented development (TOD) neighborhoods, the stations have been clustered by their Node Values in chapter 3. The main aim of the current chapter is to further classify the stations in each cluster by their Place Values. The other target of this chapter is to select stations that can serve as examples of each sub-cluster so that in the next chapter we can zoom in to the neighborhoods around the stations and scrutinize the detailed spatial distribution of the street network and urban elements.

1. Introduction

Urban spatial structure is very important in urban planning because it reflects both physical and dynamic contexts. It is defined as the relation and interaction of different urban elements (Dadashpoor & Yousefi, 2018) (Bourne, 1982), such as road networks (Spadon, Gimenes, & Rodrigues-Jr., 2017), transportation (Sasaki, 1989) (Sadayuki, 2018), distribution of buildings (Cao, Shi, & Liu, 2016), land-use patterns and economic performance (Zhu & Sun, 2017) (Zhang, Song, Nes, He, & Yin, 2019).

One of the benefits of examining the urban structure is that it allows gaining deeper insights into the evolution of the city. The fast and increasing global urbanization has resulted in the hitherto unprecedented urban growth and aggregation of people and buildings. The economic development and the increase in urban scale often leads to urban structure evolving from the monocentric to the polycentric model. Following the urban growth and the aggregation of people and buildings, balancing the development among different areas becomes a vital task for the policy makers and city planners. Accordingly, one of the purposes of introducing the concept of TOD is to mitigate and remedy the often unbalanced development of transit and land use among the neighborhoods.

“TOD emphasizes the development and opportunities provided by public transportation” (Zhang, Song, Nes, He, & Yin, 2019). In addition, a walkable neighborhood can help to enhance the success rate of TOD because it facilitate direct and proximate access to and from the transit node (Jacobson & Forsyth, 2008)

(Val, 2015) and, therefore, encourages greater use of the transit stop. It also provides the convenient and safe access to more essential destinations, amenities and services for meeting local resident's living, working and playing (Jeffrey, Boulangé, Giles-Corti, Washington, & Gunn, 2019). Therefore, a walkable neighborhood is often characterized by well-connected streets and high density of residential housing (Giles-Corti, Foster, Koohsari, Francis, & Hooper, 2015). By locating high residential density and a variety of local services, utilities, and employment around public transit stations, TOD intends to attract activities to neighborhoods around the stations in order to encourage walking and to contribute to a habitable community (Higgins & Kanaroglou, 2016) (Val, 2015) (Kamruzzaman, Baker, Washington, & Turrell, 2014).

The research on the evaluation of TOD has focused on individual transit nodes (Huang, Grigolon, Madureira, & Brussel, 2018) because the TOD plans and their implementation may vary depending on the conditions in the catchment areas[1] around different stations. Developing an approach for classifying the TOD neighborhoods is an important step for exploring the urban spatial structure and for cultivating a more profound understanding of the integrated relationships and connection among different urban elements. Classifying stations and the surrounding areas into categories is very useful for policymakers, planners and urban designers, as it allows them to simplify the complex characteristics of the areas in order to understand which neighborhoods have similar relevant properties and so to better assess their TOD potential (Reusser, Loukopoulos, Stauffacher, & Scholz, 2008) (Austin, et al., 2010) (Zemp, Stauffacher, Lang, & Scholz, 2011) (Lyu, Bertolini, & Pfeffer, 2016). The scientific assessment of the existing TOD conditions and the measurement of their heterogeneity help the policy maker and planner to uncover the potential of an area is to become transit-oriented and to explore the underlying conditions and reasons (Singh, Fard, Zuidgeest, Brussel, & van Maarseveen, 2014). Results of these analyses are crucial for facilitating the future TOD projects and enhancing the success rate of their implementation (Kamruzzaman, Baker, Washington, & Turrell, 2014).

This chapter aims at developing and exploring the station typology based on the objective features of street networks measured within close proximity to railway

1 In this chapter, the 'catchment area' is interchangeable with 'neighborhood' or 'surrounding area' around the station.

public transport (RPT) stations in metropolitan Hamburg, Germany. It is an attempt to refine and improve the measurement for investigating the complexity of street networks and Points of Interest (POI) in the TOD neighborhoods and to identify successful TOD developments.

2. Measurements and methodologies

2.1 Measurements and indicators

The characteristics of TOD can be measured by the density of points of interest (POI), the diversity of POI, the destination accessibility, and the design of street network (Cervero & Kockelman, 1997).

Density is considered to be the one of the core concepts for describing the urban spatial structure (Krehl, Siedentop, Taubenböck, & Wurm, 2016) and it is also an important factor in forming hubs or subcenters in the city (Chen, Hui, Wu, Lang, & Li, 2019). Since the size of the catchment area is fixed for all the stations, density of POI is measured directly by the number of POI.

Diversity is measured by the types of POI in the current study. The types of POI are the POI tags of Open Street Map (OSM) (OpenStreetMap contributors, 2017). By analyzing different types of POI, one can distinguish the sub-centers of neighborhoods, the residential areas, the suburban areas, etc. (Kamruzzaman, Baker, Washington, & Turrell, 2014).

Destination accessibility is often associated with walkability (Gunn, et al., 2017) and with the concept of "local living" (Badlanda, et al., 2017). Facilitating the access to essential destinations allows the residents to spend more time within their immediate neighborhood. Living close to amenities that meet their daily needs is crucial in shifting travel behavior towards more active travel modes, maximizing the use of the TOD neighborhoods and alleviating the road congestion (Jeffrey, Boulangé, Giles-Corti, Washington, & Gunn, 2019). In the current research, accessibility is defined by the average number of POI within 750 m of each node.

Detailed categorization of the indicators is presented in Table 6.1. Definition of POI defined by the tags of Open Street Map are provided in Table 6.2.

Table 6.1 Indicators for measuring the degree of walkability focusing on the street network in the TOD neighborhood.

Category	Measure		Implications to walkability
Diversity	1) Number of POI categories		Bigger is better
Density	2) Number of POI		Bigger is better
Destination accessibility	3) Average number of POI within 750m of each node		Bigger is better
Design of street network	TOPOLOGICAL MEASURE		
	Connectivity	4) Number of nodes	Bigger is better
		5) Number of links	Bigger is better
		6) Average segment length	Smaller is better
		7) Average Node Degree	Bigger is better
	Clustering	8)Average Clustering Coefficient	Higher value indicates more clusters exist in the network.
	Urban spatial order	9) Entropy of street bearing	Street network that is more grid-like exhibits less entropy.
	CENTRALITY MEASURE		
	Centrality	10) Average Closeness Centrality	Higher value indicates close proximity from a node to all other reachable nodes along the shortest path in the network.
		11) Average Betweenness Centrality	High values indicate being more frequently traversed by a larger number of the shortest paths connecting all couples of nodes in the network.

Table 6.2 Tags of point of interest from Open Street Map.

Amenities (https://wiki.openstreetmap.org/wiki/Key:amenity)	**Sustenance**	bar, BBQ, biergarten, cafe, drinking_water, fast_food, food_court, ice_cream, pub, restaurant
	Education	college, driving_school, kindergarten, language_school, library, toy_library, music_school, school, university
	Transportation	bicycle_parking, bicycle_repair_station, bicycle_rental, boat_rental, boat_sharing, bus_station, car_rental, car_sharing, car_wash, vehicle_inspection, charging_station, ferry_terminal, fuel, grit_bin, motorcycle_parking, parking, parking_entrance, parking_space, taxi
	Financial:	atm, bank, bureau_de_change
	Healthcare:	baby_hatch, clinic, dentist, doctors, hospital, nursing_home, pharmacy, social_facility, veterinary
	Entertainment, Arts & Culture:	arts_centre, cinema, community_center, fountain, planetarium, public_bookcase, social_center, studio, theatre
	Other:	bench, childcare, conference_center, marketplace, place_of_worship, police, post_box, post_depot, post_office, recycling, townhall, vending_machine, waste_basket, waste_disposal, waste_transfer_station, watering_place, water_point
Leisure (https://wiki.openstreetmap.org/wiki/Key:leisure)		amusement_arcade, bandstand, beach_resort, bird_hide, bowling_alley, dance, disc_golf_course, dog_park, escape_game, firepit, fishing, fitness_centre, fitness_station, garden, golf_course, hackerspace, horse_riding, ice_rink, marina, miniature_golf, nature_reserve, outdoor_seating, park, picnic_table, pitch, playground, resort, sauna, slipway, sports_centre, stadium, summer_camp, swimming_area, swimming_pool, tanning_salon, track, trampoline_park, water_park, wildlife_hide

Table 6.2(continued) Tags of point of interest from Open Street Map

Shops (https://wiki.openstreetmap.org/wiki/Key:shop)	**Food, beverages:**	alcohol, bakery, beverages, brewing_supplies, butcher, cheese, chocolate, coffee, confectionery, convenience, deli, dairy, farm, frozen_food, greengrocer, health_food, ice_cream, organic, pasta, pastry, seafood, spices, tea, wine, water
	Clothing, shoes, accessories:	department_store, general, kiosk, mall, supermarket, wholesale, baby_goods, bag, boutique, clothes, fabric, fashion, fashion_accessories, jewelry, leather, sewing, shoes, tailor, watches, wool
	Discount store, charity:	charity, second_hand, variety_store
	Health and beauty:	beauty, chemist, cosmetics, drugstore, erotic, hairdresser, hairdresser_supply, hearing_aids, herbalist, massage, medical_supply, nutrition_supplements, optician, perfumery, tattoo
	Do-it-yourself, household, building materials, gardening	agrarian, appliance, bathroom_furnishing, doityourself, electrical, energy, fireplace, florist, garden_centre, garden_furniture, gas, glaziery, hardware, houseware, locksmith, paint, security, trade
	Furniture and interior:	antiques, bed, candles, carpet, curtain, doors, flooring, furniture, household_linen, interior_decoration, kitchen, lamps, lighting, tiles, window_blind
	Electronics:	computer, electronics, hifi, mobile_phone, radiotechnics, vacuum_cleaner
	Outdoors and sport, vehicles:	atv, bicycle, boat, car, car_repair, car_parts, caravan, fuel, fishing, golf, hunting, jetski, military_surplus, motorcycle, outdoor, scuba_diving, ski, snowmobile, sports, swimming_pool, trailer, tyres
	Art, music, hobbies:	art, collector, craft, frame, games, model, music, musical_instrument, photo, camera, trophy, video, video_games
	Stationery, gifts, books, newspapers:	anime, books, gift, lottery, newsagent, stationery, ticket
	Others:	bookmaker, cannabis, copyshop, dry_cleaning, e-cigarette, funeral_directors, laundry, money_lender, party, pawnbroker, pet, pet_grooming, pest_control, pyrotechnics, religion, storage_rental, tobacco, toys, travel_agency, vacant, weapons, outpost

Design aspect is evaluated by the measures that are frequently used in the study of street network studies. It is included in the measurement of the TOD characteristics because the network structural characteristics have been found to have significant relationship with the functional or social urban aspects, such as services localization (Peponis, Allen, French, Scoppa, & Brown, 2007), population density (Tang, 2003), as well as walking flow and urbanity (Omer & Jiang, 2008) (Van Nes & ZhaoHui, 2009) (Hamaina, Leduc, & Moreau, 2011). Computational network analysis will be carried out to calculate the topological and centrality measures of the street network, which is retrieved from the OSM (OpenStreetMap contributors, 2017). We have used some of the indicators for analyzing transportation network in chapter 2 and 3. In the current chapter, we include more measurement and focus on their meanings to street network and pedestrian movement.

1) Topological measurements

Topological measurements evaluate the configuration, connectivity and robustness of the network structure and show how these characteristics and properties are distributed. They measure connectivity and complexity of the network by assessing how thoroughly the nodes are linked together. Topological measures in the current research are divided into the following three subcategories of attributes: connectivity, Clustering Coefficient and urban spatial order. Each category of the attributes is the combined behavior of a group of indicators.

i) ***Connectivity measure***

Connectivity measure is “the minimum number of nodes or edges that must be removed from a connected graph to disconnect it” (Boeing, 2017) and how easy or difficult it is for any two nodes to form a connection. Street connectivity can also be used as a measure of the following attributes.

Resilience. Higher connectivity is more robust against failures, disruptions or attacks because if offers more alternative routing choices.

Pedestrian accessibility to transit stops, services and utilities. Less-connected streets increase the route distance for the pedestrian. “Appropriate connection between minor and pedestrian routes to major transit streets is critical for facilitating effective and efficient access to public transit” (Sharifi, 2019).

Choice of traffic mode. The decisions to walk or bike are often affected by people’s “perception of certain trip length thresholds” (Larco, 2016). Combining higher connectivity with other features, including high levels of mixed-use development and high density, can influence on people’s choice of traffic mode, shift their travel behavior toward more active modes and subsequently reduce transport-related Greenhouse Gas (GHG) emissions (Ewing & Cervero, 2010).

Social and health-related benefits. High connectivity also facilitates the access to local amenities and employment by walking. Higher concentration of walking population attracts more job opportunities in the neighborhood. Therefore, higher connectivity is associated with social and health-related benefits (Sharifi, 2019).

The number of nodes, number of links, average segment length and average Node Degree are commonly used measures of connectivity.

- **Number of nodes and links**

  Higher number of nodes and links are associated with higher connectivity.

- **Average segment length**

  Street segment length is a measure of distance between nodes. Average segment length is defined as the average length of the shortest segments between all possible pairs of nodes. Lower values indicate better connectivity and walkability.

- **Average Node Degree**

  Node degree is defined as the total number of links branching off or concurring in the node. The average Node Degree of a network is a measure that gave an indication of the organization, configuration, and overall **level of connectivity** of the network. Higher value of the average node degree means better communication between the nodes. In terms of walkability, average Node Degree provides the information on route option and is found to be positively correlated to walking frequency (Pooley, et al., 2013)

ii) Clustering Coefficient (C)

Within the network, there are usually some subsets of the system, which are referred to as clusters, that share some common set of properties. These clusters often have important influence on the network's makeup. Clustering Coefficient is a measurement that reveals the topological structure and distribution of these clusters. Higher value indicates more clusters exist in the network. Networks can be categorized according to whether these clusters are centralized, decentralized, or randomly distributed.

iii) Urban spatial order & entropy of street bearing

In this research, urban spatial order, which quantifies the extent to which a network is ordered according to a single grid (Boeing, 2019), is measured by the entropy of the street bearing. Street network that is more grid-like exhibits less entropy.

2) Centrality measures

The degree of connectivity to a given node in a network is closely intertwined with broader concept of centrality, which is a measure that captures how influential or significant a node is within the overall network. Previously in chapter 3, we have employed the same centrality measures to analyze the transportation network. In this chapter, the focus is on the meaning and implication of these measures to the relationship between the street network and the following functions.

Resilience and robustness. Nodes and links with high centrality values play very significant roles in the network system for the service and facilities to be reachable. However, if these important nodes and links are obstructed, the reachability and continuity in the system would be undermined and the traffic volume may not be appropriately distributed by alternative streets (Mattsson & Jenelius, 2015). Therefore, from the perspective of resilience and robustness, the design target of the network is to avoid polarizing the accessibility in the system and the dependence on the highly central nodes and links (Aydin, Duzgun, Wenzel, & Heinimann, 2018). "To avoid such a polarization, it is suggested that the extent of centrality is determined using a hierarchic approach that follows *power law distribution***.** This implies having small, medium, and large numbers of high-, moderate-, and low-centrality nodes/links in the system, respectively" (Sharifi, 2019).

Economic activity. Street centrality has been found to have strong and positive correlations with economic activity (Remali, Porta, Romice, & Abudib, 2015) (Porta, et al., 2012) (Liu, Wei, Jiao, & Wang, 2016). "Areas that have higher Betweenness Centrality values are unique locations in the built environment that have a higher potential of being traversed by people and freight trips to other locations in the city. This high potential to attract through traffic increases the possibility of generating business opportunities in areas with high Betweenness Centrality" (Sharifi, 2019).

Each centrality measurement captures different types of importance of a node or link in the street network. The calculation of these indicators has been presented in chapter 3, and here we highlight their implications for the street network.

- **Closeness Centrality (C_c)**

Closeness Centrality is an indicator of **accessibility** because it indicates the ability to reach a node from any location in the network (Porta, Crucitti, & Latora, 2006). Since higher Closeness Centrality indicates higher accessibility, placing services and utilities in the location with high Closeness Centrality reduces spatial disconnection between places (Porta, et al., 2009). This benefit is of significant importance when choosing the location for a service, function, facility or amenity in the street network, which is the topic we will deal with in the next chapter.

- **Betweenness centrality (C_b)**

Betweenness Centrality measures whether a location is the **intermediary** between others. A location with higher Betweenness Centrality means it lies among many other locations and is critical for maintaining the functionality of the street network. However, this also means that if such a node or link is disrupted, this will cause serious failure across the system (Akbarzadeh, Memarmontazerin, Derrible, & Salehi Reihani, 2019). Therefore, for the perspective of resilience and robustness, street network structure with extremely high Betweenness Centrality values, which exist in star- or wheel-shaped street networks with a single dominant node, should be avoided (Kermanshah & Derrible, 2017).

In total, 11 measures listed in Table 6.1 are derived and categorized based on the proposed framework for each catchment area around the station. The determination of the size of the catchment area has been discussed in chapter 4. As explained there, the size of the catchment areas around stations is defined as a square of 1500*1500m^2 because previous researches have shown that this distance is related to measures like typology analyses, physical activity and walking trips (Val, 2015) (Gunn, et al., 2017).

3) Correlation of indicators

It should be noted that the correlations between indicators is only based on the case of Hamburg. In the future, it would be interesting to compare these correlations among cities with different spatial configuration.

Table 6.3 presents the statistical correlation between indicators in order to find whether they are correlated and influential to each other. The patterns of correlation can be broadly divided into the following groups.

First of all, the correlation patterns of the three indicators related to POI are quite similar to each other. They are **significantly** related to all indicators except for **average Node Degree** and **average Clustering Coefficient**. They are positively correlated with the **number of nodes, number of links** and **entropy of street bearing**. They are negatively correlated with **average Betweenness Centrality**. Only **POI diversity** is significantly and negatively correlated with **average Closeness Centrality.** This means that in the RPT neighborhoods in Hamburg where there are larger numbers of nodes and links, higher level of street bearing entropy and lower level of average Betweenness Centrality, there are also higher levels of accessibility, density and diversity of POI.

Secondly, the following three indicators are significantly correlated to only a few of other indicators.

- **Average Node Degree** is only significantly and positively related to one indicator, the **number of links.** This means that neighborhoods with more links, i.e. street segments, also have higher average node degree.
- **Average Clustering Coefficient** is only significantly and positively related to **POI accessibility, POI density, and POI diversity.** This is an interesting observation and deserves further investigation to examine whether larger number of clusters in the street network actually benefits the local business. **Average Clustering Coefficient** is also significantly and negatively correlated to **average segment length**. This may indicate that shorter segments in the neighborhoods generates more clusters in the network.
- **Average Closeness Centrality** is only significantly and positively related to **average Betweenness Centrality.** It is negatively related to the **number of nodes**, **entropy of street bearing** and **POI diversity**.

Thirdly, the following indicators are significantly correlated to most other indicators except for **average Node Degree** and **average Clustering Coefficient.**

- **Number of nodes** is positively correlated with **number of links**, **entropy of street bearing**, **POI accessibility**, **POI density**, and **POI diversity**. It is negatively correlated with **average segment length**, **average Closeness Centrality** and average **Betweenness Centrality**.

- **Entropy of street bearing** is positively correlated with **number of nodes, number of links, POI accessibility, POI density, and POI diversity.** It is negatively correlated with **average segment length, average Closeness Centrality, average Betweenness Centrality.**
- **Average Betweenness Centrality** is positively correlated with **average segment length.** It is negatively correlated with **number of nodes, number of links, entropy of street bearing, average Closeness Centrality, average Betweenness Centrality, POI accessibility, POI density, and POI diversity.**

Finally, the following indicators are significantly correlated to most of the indicators
except for **average Closeness Centrality**.

- **Number of links** is positively correlated with **number of nodes, average Node Degree, entropy of street bearing, POI accessibility, POI density, and POI diversity**. It is negatively correlated with **average segment length and average Betweenness Centrality.**
- **Average segment length** is positively correlated with **average Betweenness Centrality.** It is negatively correlated with **number of nodes, number of links, entropy of street bearing, average Clustering Coefficient, POI accessibility, POI density, and POI diversity.**

It should be noted that the correlations between indicators is only based on the case of Hamburg. In the future, it would be interesting to compare these correlations among cities with different spatial configuration.

Table 6.3 Correlation pairs between indicators.

	Number of nodes	Number of links	Average Node degree	Average segment length	Entropy of street bearing	Average Clustering Coefficient	Average Closeness Centrality	Average Betweenness Centrality	POI accessibility	POI density	POI diversity
Number of nodes	1	0.98***	0.18	-0.81***	0.94***	0.20	-0.26*	-0.87***	0.79***	0.77***	0.82***
Number of links	0.98***	1	0.38***	-0.81***	0.92***	0.14	-0.18	-0.83***	0.78***	0.73***	0.76***
Average Node Degree	0.18	0.38***	1	-0.16	0.19	-0.22	0.19	-0.13	0.17	0.05	-0.04
Average segment length	-0.81***	-0.81***	-0.16	1	-0.81***	-0.40***	-0.02	0.76***	-0.70***	-0.67***	-0.68***
Entropy of street bearing	0.94***	0.92***	0.19	-0.81***	1	0.18	-0.35***	-0.92***	0.67***	0.67***	0.81***
Average Clustering Coefficient	0.20	0.14	-0.22	-0.40***	0.18	1	0.05	-0.12	0.30**	0.33**	0.23*
Average Closeness Centrality	-0.26*	-0.18	0.19	-0.02	-0.35***	0.05	1	0.30**	-0.06	-0.16	-0.28**

Average Betweenness Centrality	-0.87***	-0.83***	-0.13	0.76***	-0.92***	-0.12	0.30**	1	-0.63***	-0.66***	-0.78***
POI accessibility	0.79***	0.78***	0.17	-0.70***	0.67***	0.30**	-0.06	-0.63***	1	0.96***	0.80***
POI density	0.77***	0.73***	0.05	-0.67***	0.67***	0.33**	-0.16	-0.66***	0.96***	1	0.82***
POI diversity	0.82***	0.76***	-0.04	-0.68***	0.81***	0.23*	-0.28**	-0.78***	0.80***	0.82***	1

*** Correlation is significant at 0.01 level; **Correlation is significant at 0.05 level; *Correlation is significant at 0.1 level

2.2 Methodologies

Descriptive statistics for the measures are computed and cluster analysis is used to group the stations in order to determine their levels of walkability. In this chapter, Affinity Propagation (AP) (Frey & Dueck, 2007) is employed to group the TOD neighborhoods of similar attributes. AP chooses the number of clusters based on the data and it doesn't require specifying the number of clusters in advanced. The AP algorithm forms clusters by sending messages between pairs of instances until convergence. "Each data point sends messages to all other points informing its targets of each target's relative attractiveness to the sender. Each target then responds to all senders with a reply informing each sender of its availability to associate with the sender, given the attractiveness of the messages that it has received from all other senders. Senders reply to the targets with messages informing each target of the target's revised relative attractiveness to the sender, given the availability messages it has received from all targets. The message-passing procedure proceeds until a consensus is reached. Once the sender is associated with one of its targets, that target becomes the point's exemplar. All points with the same exemplar are placed in the same cluster. The exemplars are identified as those most representative of other samples” (Thavikulwat, 2008).

The 11 indicators identified in Table 6.1 are applied for the AP clustering. The “exemplars” defined by AP represents the average characteristics of the neighborhoods in the same cluster. This is an important step because these exemplars will be used as the target neighborhoods and be further investigated in detail in the next chapter.

The process of clustering TOD neighborhoods can be divided into the following steps.

- Step1: Download street network data of the TOD neighborhoods from OSM using the function of *osmnx.graph_from_point* in Python library of OSMnx
- Step2: Calculate the street orientation using the function of *osmnx.add_edge_bearings* from the Python library of OSMnx. Calculate the entropy of street orientation using the function of *entropy* from the python library of scipy.stats.
- Step3: Calculate the number of nodes, number of links, average segments length, average Node Degree using the function of *osmnx.basic_stats* in Python library of OSMnx
- Step4: Calculate the average Clustering Coefficient, average Closeness Centrality, average Betweenness centrality using the function of *osmnx.extended_stats* in Python library of OSMnx
- Step5: Retrieve the coordinate point of interest (POI) using the function of *osmnx.pois_from_point* in Python library of OSMnx
- Step6: Calculate the density of POI by calculating the number of POI within the neighborhood.
- Step7: Calculate the diversity of POI by calculating the types of amenities within the neighborhood
- Step8: Calculate accessibility of POI by searching for the nearest amenities to each node using the function of *pandana.network.nearest_pois* in the Python library of Pandana. Each node then has the information about how many POI are within 750m from it. The sum of this information is then divided by the total number of nodes to form the accessibility of POI of each neighborhood.
- Step9: Cluster TOD neighborhoods using the function of *sklearn.cluster.AffinityPropagation* in the Python library of scikit-learn
- Step10: Plot the POI and the cluster of POI using the Python library of

matplotlib.

3. Result

3.1 Numbers of sub-cluster and list of stations in each sub-cluster

By applying the Affinity Propagation, we aim to achieve two targets. Firstly, within each Node-Value cluster, we search for the sub-clusters that can be further grouped together based on their Place Value. Secondly, we identify the “exemplars” that are representative for each sub-cluster and scrutinize the detailed distribution of street network and POI in these exemplar neighborhoods in the next chapter.

Results of Affinity Propagation indicates that stations in Node-Value-cluster-0 can be further divided into 3 sub-clusters, which are named Cluster 0-0, Cluster 0-1 and Cluster 0-2 in

Table 6.4; stations in Node-Value-cluster-1 can be further divided into 4 sub-clusters, which are Cluster 1-0, Cluster 1-1, Cluster 1-2 and Cluster 1-3 in

Table 6.5; stations in Node-Value-cluster-2 can be further divided into 2 sub-clusters, which are Cluster 2-0 and Cluster 2-1 in

Table 6.6. The exemplar of each sub-cluster is highlighted with gray background and their distribution of street network and POI will be examined further in the following chapter.

Table 6.4 Stations in each sub-cluster of Node-Value cluster 0.

(Exemplar of each group is lighted with gray background.)

Cluster 0-0	Cluster 0-1	Cluster 0-2
Altona	Agathenburg	Billstedt
Buxtehude	Ahrensburg Ost	Blankenese
Dammtor (Messe/CCH)	Ahrensburg West	Diebsteich
HafenCity Universität	Aumühle	Elbbrücken
Harburg	Buchenkamp	Hamburg Airport (Flughafen)
Harburg Rathaus	Buckhorn	Hammerbrook (City Süd)
Holstenstraße	Dollern	Heimfeld
Neugraben	Fischbek	Horneburg
Norderstedt Mitte	Großhansdorf	Joachim-Mähl-Straße
Sternschanze (Messe)	Halstenbek	Neu Wulmstorf
Überseequartier	Hoheneichen	Neuwiedenthal
	Hoisbüttel	Ohlsdorf
	Iserbrook	Pinneberg
	Kiekut	Rissen
	Krupunder	Stade
	Mümmelmannsberg	Veddel (BallinStadt)
	Neukloster	Wedel
	Niendorf Nord	Wilhelmsburg
	Ohlstedt	
	Reinbek	
	Sülldorf	
	Schippelsweg	
	Schmalenbeck	
	Thesdorf	
	Volksdorf	
	Wohltorf	

Table 6.5 Stations in each sub-cluster of Node-Value cluster 1.

(Exemplar of each group is lighted with gray background.)

Cluster 1-0	Cluster 1-1	Cluster 1-2	Cluster 1-3
Alte Wöhr (Stadtpark)	Allermöhe	Alter Teichweg	Gänsemarkt
Barmbek	Alsterdorf	Bahrenfeld	Hauptbahnhof
Baumwall (Elbphilharmonie)	Billwerder-Moorfleet	Berne	Hauptbahnhof Süd
Bergedorf	Eidelstedt	Borgweg (Stadtpark)	Meßberg
Berliner Tor	Elbgaustraße	Fuhlsbüttel	Mönckebergstraße
Christuskirche	Farmsen	Garstedt	Rathaus
Dehnhaide	Fuhlsbüttel Nord	Hallerstraße	Rödingsmarkt
Emilienstraße	Hagenbecks Tierpark	Hasselbrook	Steinstraße
Eppendorfer Baum	Hagendeel	Hoheluftbrüke	
Feldstraße (Heiligengeistfeld)	Hochkamp	Hudtwalckerstraße	
Friedrichsberg	Kiwittsmoor	Klein Borstel	
Habichtstraße	Klein Flottbek (Botanischer Garten)	Klosterstern	
Hamburger Straße	Kornweg (Klein Borstel)	Landwehr	
Kellinghusenstraße	Langenfelde	Langenhorn Markt	
Lattenkamp (Sporthalle)	Langenhorn Nord	Niendorf Markt	
Lohmühlenstraße	Meiendorfer Weg	Ochsenzoll	
Lübecker Straße	Merkenstraße	Othmarschen	
Lutterothstraße	Mittlerer Landweg	Poppenbüttel	
Messehallen	Oldenfelde	Richtweg	
Mundsburg	Rothenburgsort	Ritterstraße	
Nettelnburg	Steinfurther Allee	Saarlandstraße	
Osterstraße	Stellingen (Arenen)	Sengelmannstraße (City Nord)	
Rubenkamp (City Nord)	Tiefstack	Sierichstraße	
Schlump	Trabrennbahn	Straßburger Straße	
St. Pauli	Wandsbek-Gartenstadt	Wartenau	
Stephansplatz (Oper/CCH)	Wellingsbüttel		
Uhlandstraße			
Wandsbek Markt			
Wandsbeker Chaussee			

Table 6.6 Stations in each sub-cluster of Node-Value cluster 2.

(Exemplar of each group is lighted with gray background.)

Cluster 2-0	Cluster 2-1
Burgstraße	Hauptbahnhof Nord
Hammer Kirche	Jungfernstieg
Horner Rennbahn	Stadthausbrücke
Königstraße	
Landungsbrücken	
Legienstraße	
Rauhes Haus	
Reeperbahn	

3.2 Characterizing each sub-cluster based on Place Value

The main purpose of this section is to assign Place Value to each sub-cluster based on their characteristics. The characteristics are identified by 1) spatial distribution and 2) statistical distribution of the measurement.

1.1.i) Node-Value-cluster 0

The spatial distribution of the three sub-clusters in Node-Value-cluster-0 is mapped in Figure 6.1. In chapter 3 we have learned that, compared to other clusters, stations in Node-Value-cluster-0 are mostly distributed in the middle to outer suburbs and have the lowest Node Value. After further dividing the Node-Value-cluster-0 into three sub-clusters based on their Place Values, the results show that stations of

- Cluster 0-0 are predominantly located in the inner city, with some exceptions in the middle suburbs.
- Cluster 0-1 are mainly distributed in the middle and outer suburbs.
- Cluster 0-2 are distributed all over, including inner city, middle and outer suburbs.

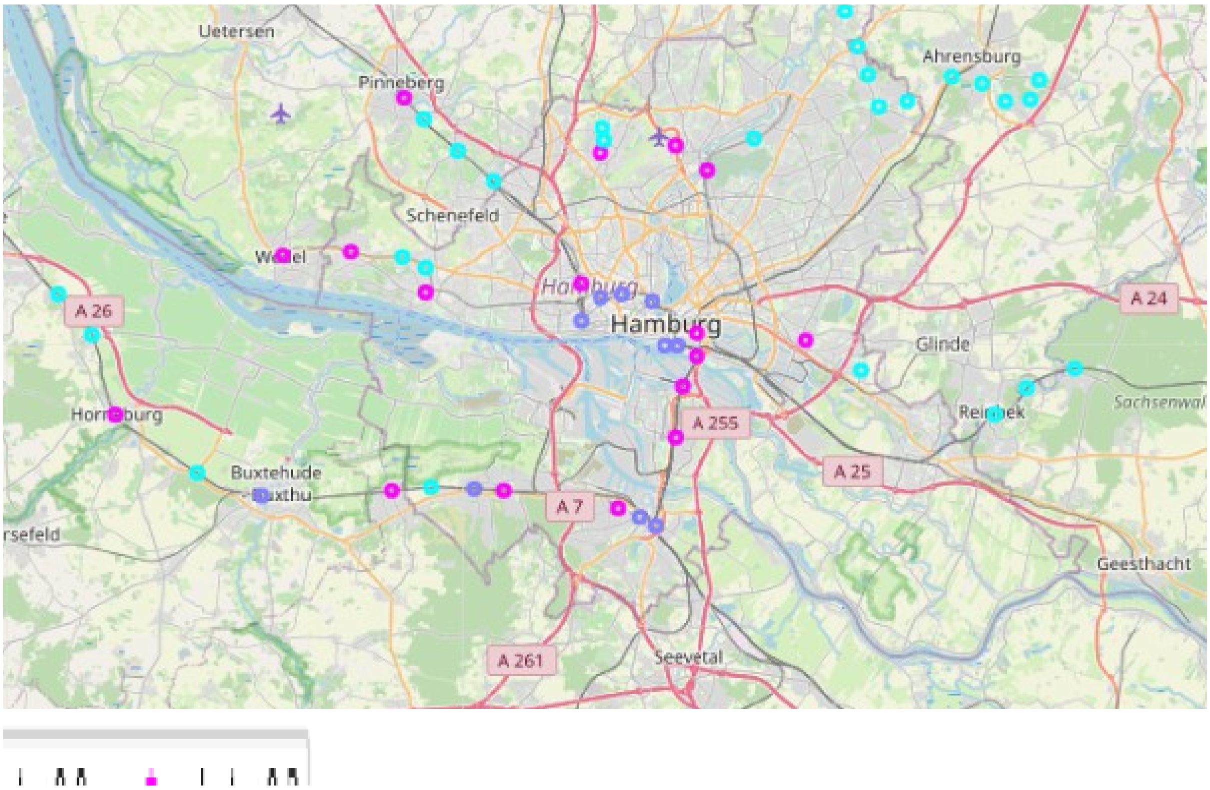


Figure 6.1 Spatial distribution of each sub-cluster in Node-Value-cluster 0.

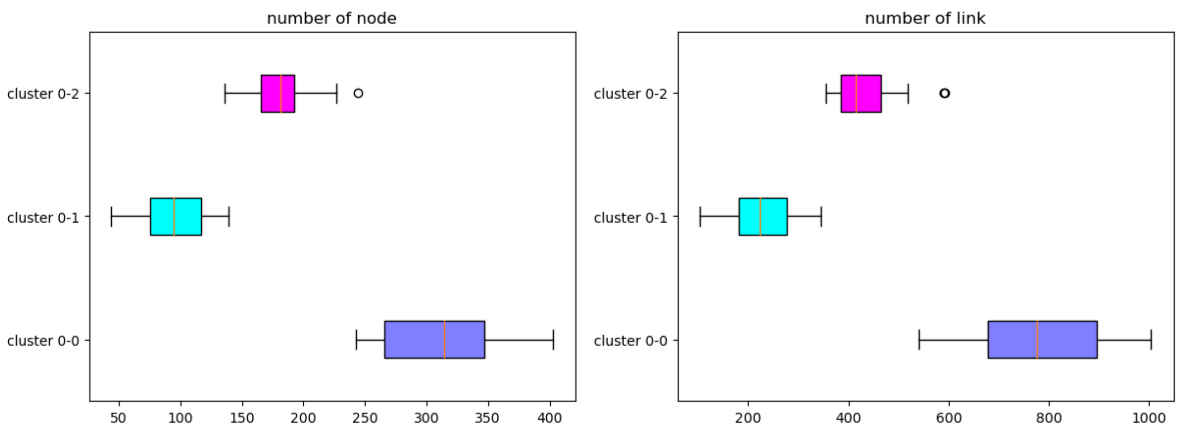
Table 6.7 Descriptive statistics of each sub-cluster in Node-Value-cluster-0.

	All station in cluster 0		Cluster 0-0		Cluster 0-1		Cluster 0-2	
	mean	std	**mean**	std	**mean**	**std**	**mean**	std
Number of nodes	**165.24**	87.90	**308.09**	50.65	**93.62**	26.28	**181.39**	26.27
Number of links	**406.91**	230.57	**786.18**	152.97	**227.12**	66.27	**434.83**	72.81
Average Node Degree	**4.88**	0.44	**5.12**	0.75	**4.84**	0.30	**4.79**	0.34
Average segment length	**99.22**	27.13	**65.62**	13.21	**120.71**	18.94	**88.73**	12.43
Entropy of street bearing	**5.67**	0.50	**6.33**	0.20	**5.24**	0.30	**5.88**	0.17
Average Clustering Coefficient	**0.07**	0.03	**0.08**	0.02	**0.06**	0.03	**0.07**	0.03
Average Closeness Centrality	**0.0010**	0.0002	**0.0010**	0.0002	**0.0011**	0.0002	**0.0010**	0.0001
Average Betweenness Centrality	**0.07**	0.02	**0.05**	0.01	**0.09**	0.02	**0.06**	0.01
POI_Accessibility	**63.03**	69.03	**171.20**	80.83	**22.63**	14.50	**55.29**	29.23
POI_Density	**146.75**	163.88	**399.82**	193.20	**46.42**	25.48	**137.00**	73.89
POI_Diversity	**23.31**	10.06	**36.18**	6.60	**15.96**	6.73	**26.06**	5.61

Next, the sub-clusters can be characterized by the statistical distribution of the indicators. Based on the criteria we have set up in Table 6.1, the results in Table 6.7

and Figure 6.2 show that cluster 0-0 has the highest Place Value because it has the highest value in terms of number of nodes, number of links, average Node Degree and entropy of street bearing. Also, it has the lowest value of average segment length and Betweenness Centrality. This means that the street networks in the neighborhoods of these stations are well connected and more walkable than the stations in the other two groups. This group of stations also has highest value in terms of accessibility, density and diversity of POI. Cluster 0-1 has the lowest Place Value, while cluster 0-2 has the middle Place Value in cluster 0.

In sum, with regard to Place Value, cluster 0-0 > cluster 0-2 > cluster 0-1.



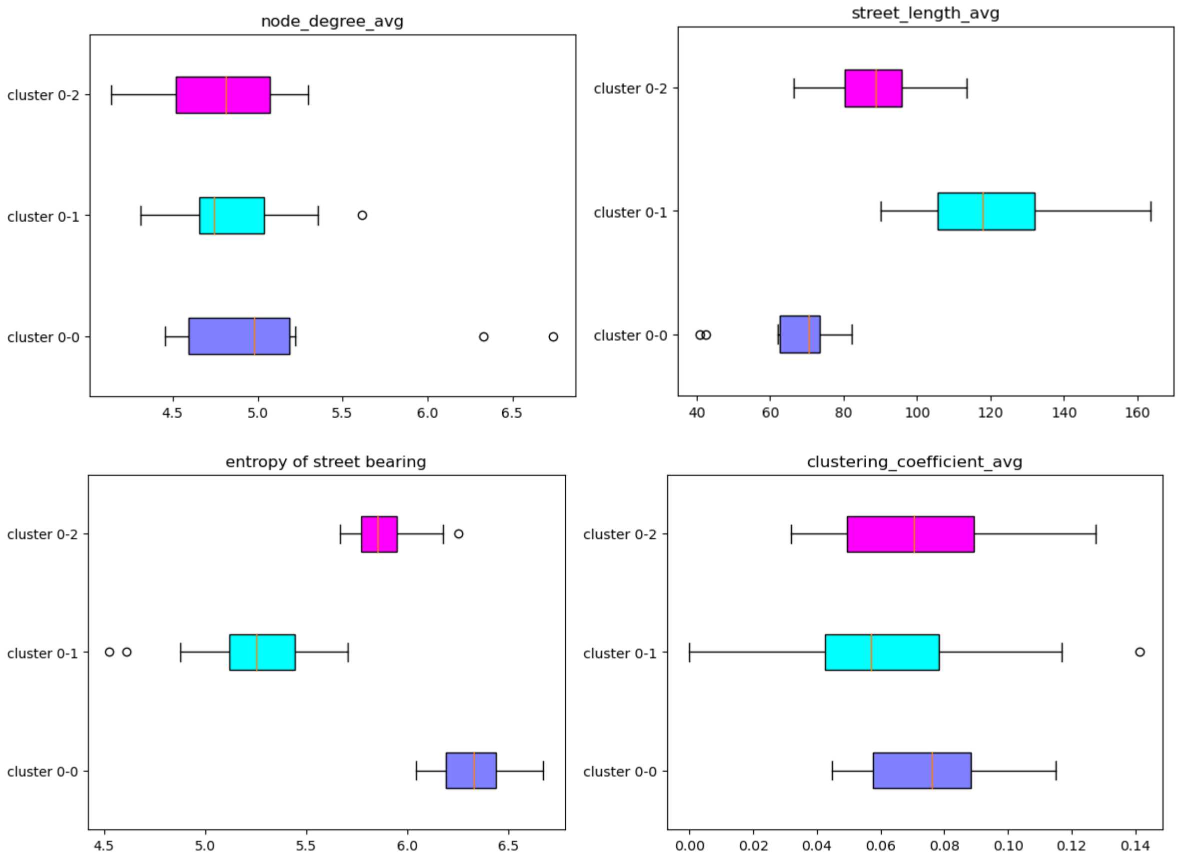
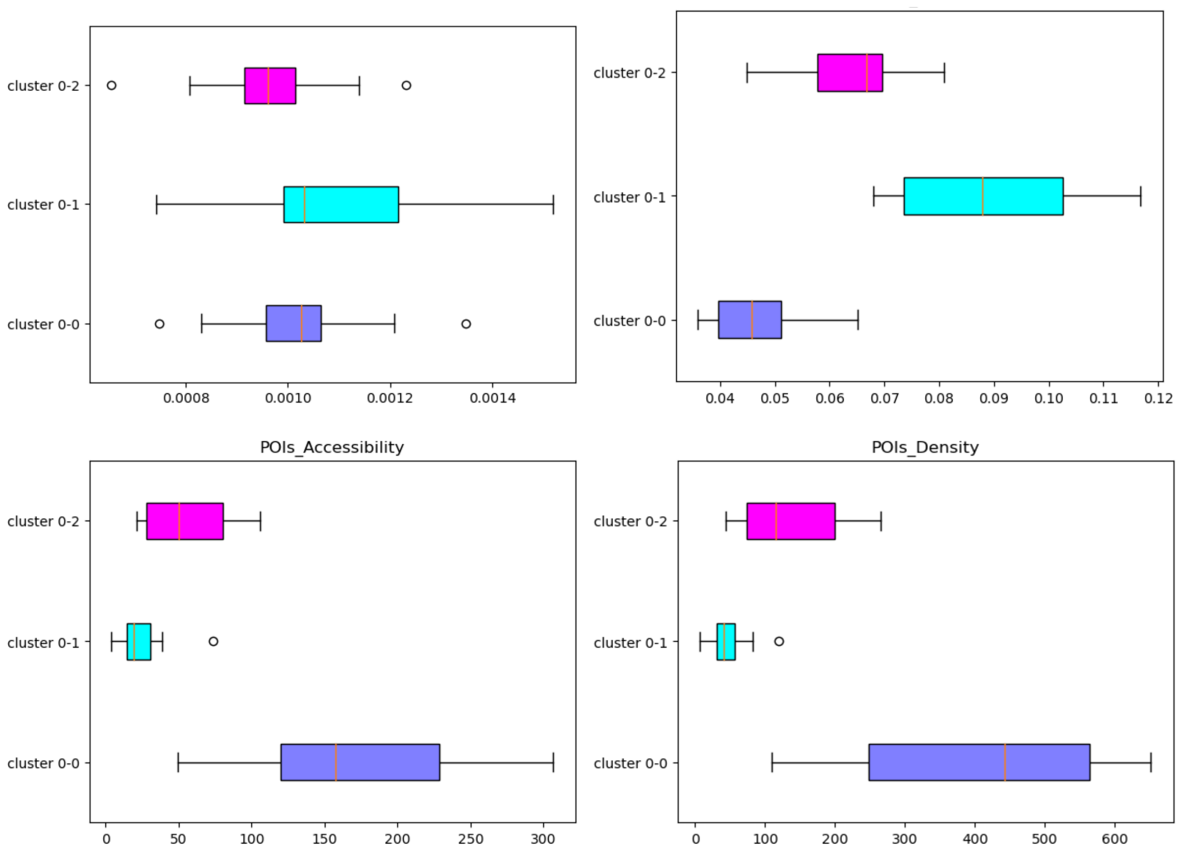


Figure 6.2 Statistical distribution of the characteristics of each group in Node-Value-cluster-0.



cluster 0-2
cluster 0-1
cluster 0-0
0.0008
0.0010
0.0012
0.0014
cluster 0-2
cluster 0-1
cluster 0-0
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
POIs_Accessibility
cluster 0-2
cluster 0-1
cluster 0-0
0
50
100
150
200
250
300
POIs_Density
cluster 0-2
cluster 0-1
cluster 0-0
0
100
200
300
400
500
600

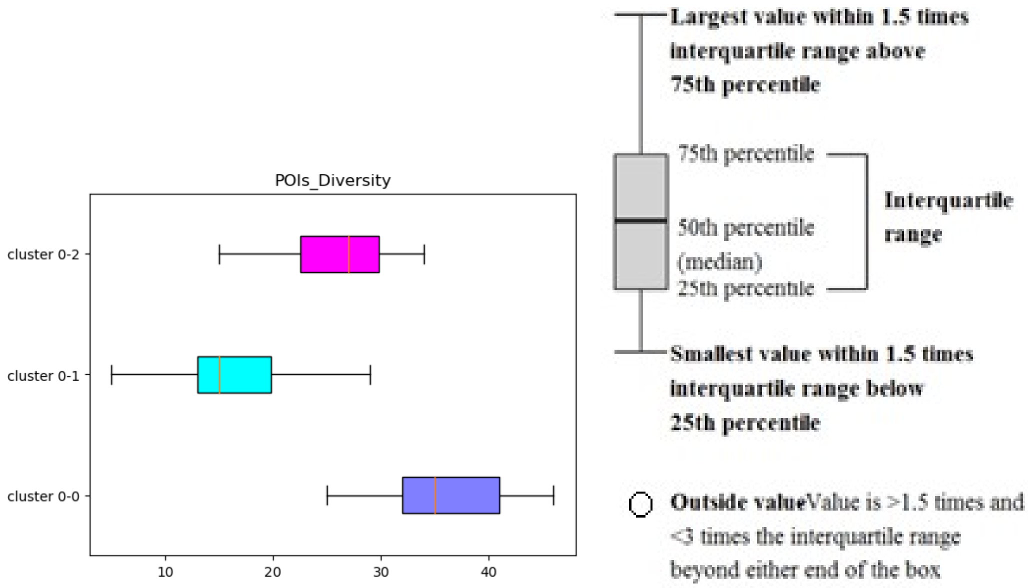
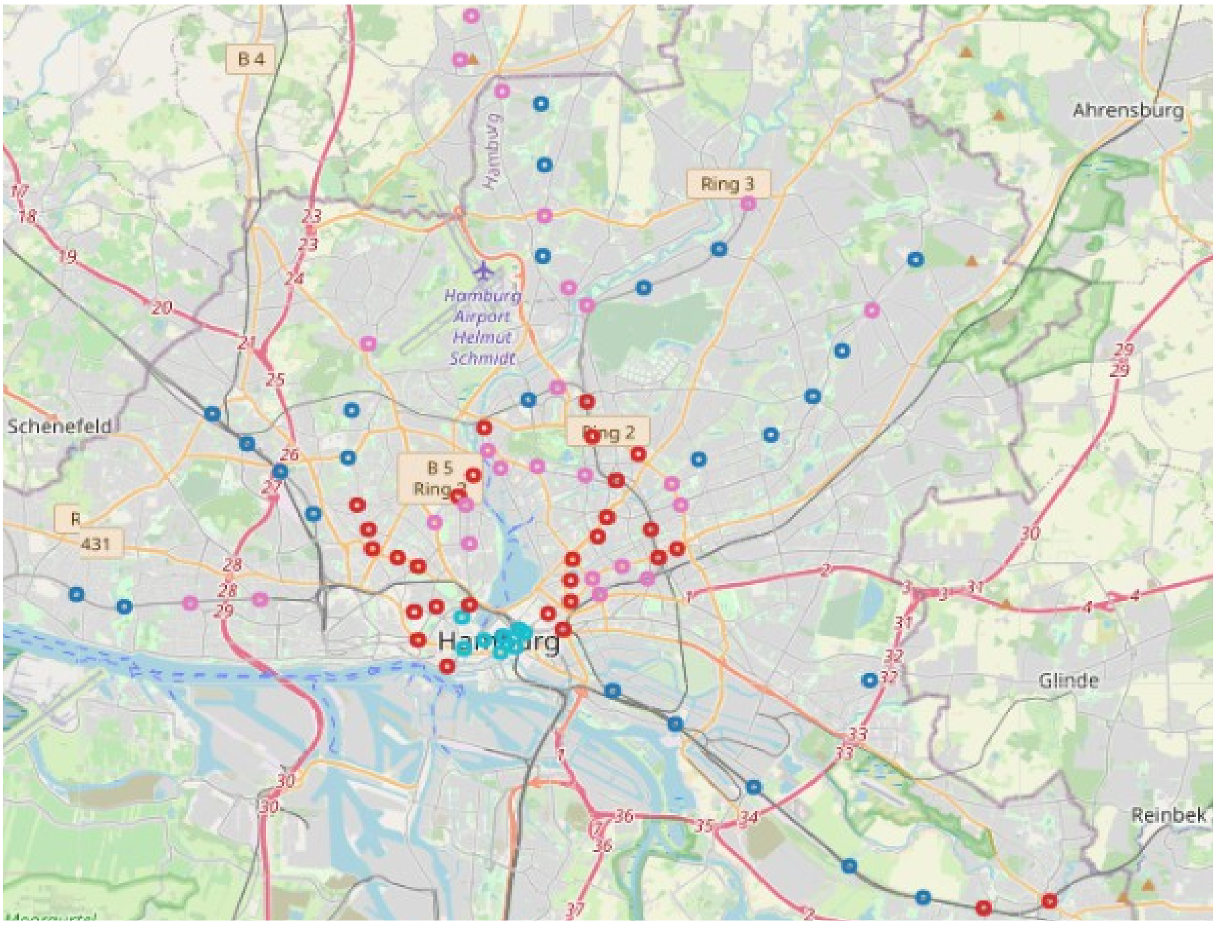


Figure 6.2 (continued) Statistical distribution of the characteristics of each group in Node-Value-cluster-0.



1.1.ii) Node-Value-cluster 1

Figure 6.3 Spatial distribution of each sub-cluster in Node-Value-cluster-1.

The spatial distribution of the three sub-clusters in Node-Value-cluster-1 is mapped in Figure 6.3. In chapter 3 we have learned that, compared to other clusters, stations in Node-Value-cluster-1 are mostly distributed in the inner city and middle suburb. After further dividing the cluster into 4 sub-clusters based on their Place Values, the results show that stations of

- Cluster 1-0 are predominantly located in the middle suburb, with two exceptions in the outer suburbs.
- Cluster 1-1 are mainly distributed in the outer suburb.
- Cluster 1-2 are mainly distributed in the middle and outer suburbs.
- Cluster 1-3 are distributed in the inner city.

Next, the sub-clusters can be characterized by the statistical distribution of the indicators. Based on the criteria we have set up in Table 6.1, the results in Table 6.8 and Figure 6.4 show that cluster 1-3 has the highest Place Value because it has the highest value in terms of number of nodes, number of links, average Node Degree and entropy of street bearing. Also, it has the lowest value of average segment length and Betweenness Centrality. This group of stations also has highest value in terms of accessibility, density and diversity of POI. Cluster 1-1 has the lowest Place Value because it has the lowest values in terms of number of nodes, number of links and entropy of street bearing. Also, it has the highest value of average segment length, Closeness Centrality and Betweenness Centrality.

In sum, with regard to Place Value, cluster 1-3 > cluster 1-0 > cluster 1-2 > cluster 1-1.

Table 6.8 Descriptive statistics of each sub-cluster in Node-Value-cluster-1.

	All station in cluster 1		Cluster 1-0		Cluster 1-1		Cluster 1-2		Cluster 1-3	
	mean	std	**mean**	std	**mean**	std	**mean**	std	**mean**	std
Number of nodes	**224.84**	128.56	**264.83**	48.78	**104.19**	33.57	**200.88**	29.67	**546.88**	87.08
Number of links	**523.98**	337.12	**595.86**	123.67	**239.27**	82.16	**455.40**	62.69	**1403.00**	302.31
Average Node Degree	**4.58**	0.37	**4.49**	0.27	**4.54**	0.47	**4.55**	0.21	**5.09**	0.33
Average segment length	**86.53**	21.71	**75.17**	10.75	**108.85**	18.70	**86.32**	13.86	**55.81**	4.99
Entropy of street bearing	**5.88**	0.58	**6.17**	0.16	**5.21**	0.53	**5.94**	0.15	**6.80**	0.11
Average Clustering Coefficient	**0.08**	0.03	**0.09**	0.02	**0.08**	0.04	**0.09**	0.02	**0.08**	0.01

Average Closeness Centrality	**0.00098**	0.00017	**0.00098**	0.00010	**0.00101**	0.00026	**0.00096**	0.00016	**0.00098**	0.00003
Average Betweenness Centrality	**0.06188**	0.02498	**0.04959**	0.00599	**0.08828**	0.02951	**0.05859**	0.00653	**0.03091**	0.00277
POI_Accessibility	**122.82**	105.78	**156.80**	49.32	**35.90**	33.93	**87.67**	28.84	**391.96**	48.21
POI_Density	**332.86**	272.05	**444.48**	139.06	**94.42**	69.79	**240.44**	89.73	**992.00**	87.63
POI_Diversity	**31.73**	10.50	**38.93**	4.55	**19.42**	6.87	**31.60**	5.35	**46.00**	3.12

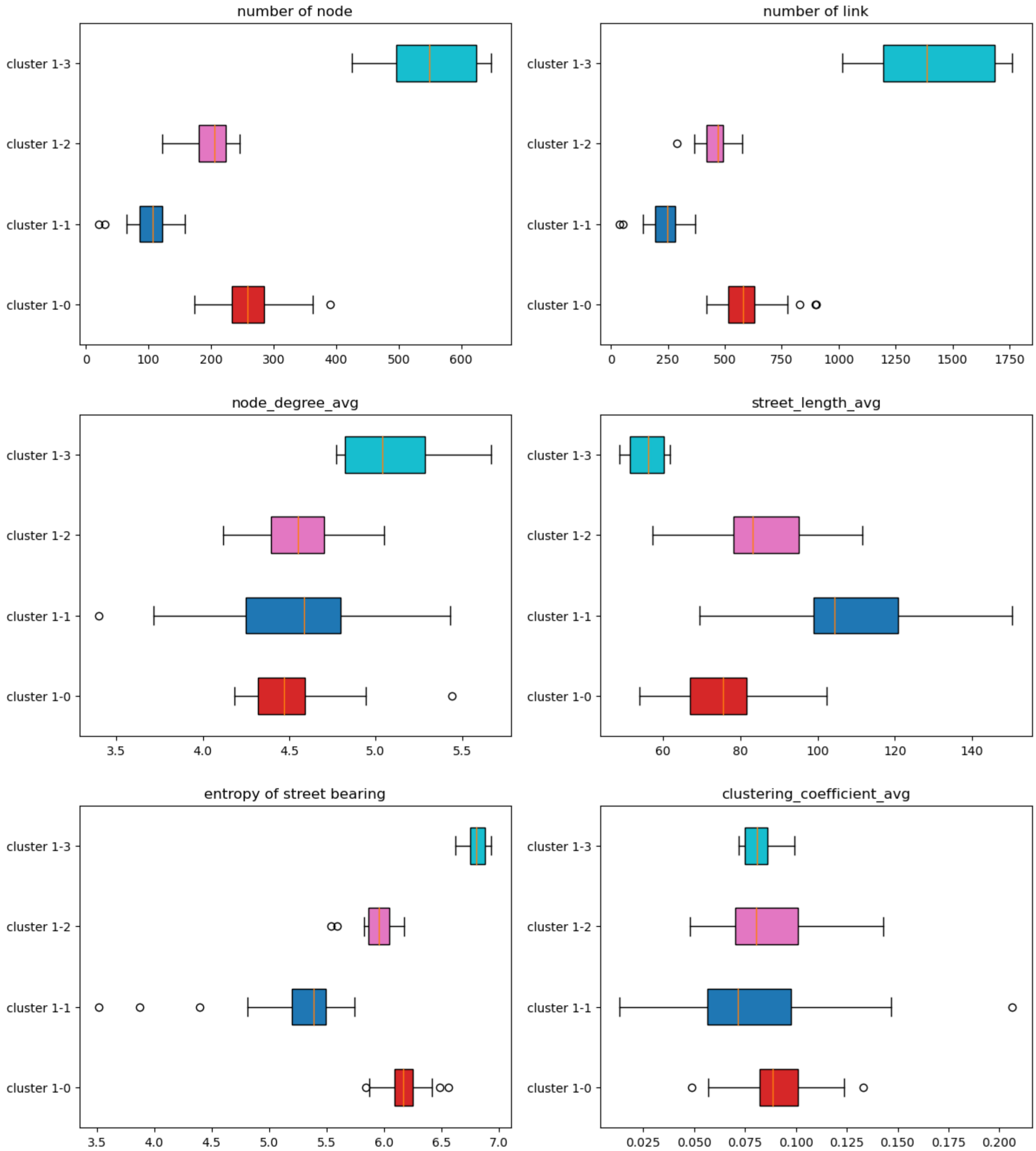
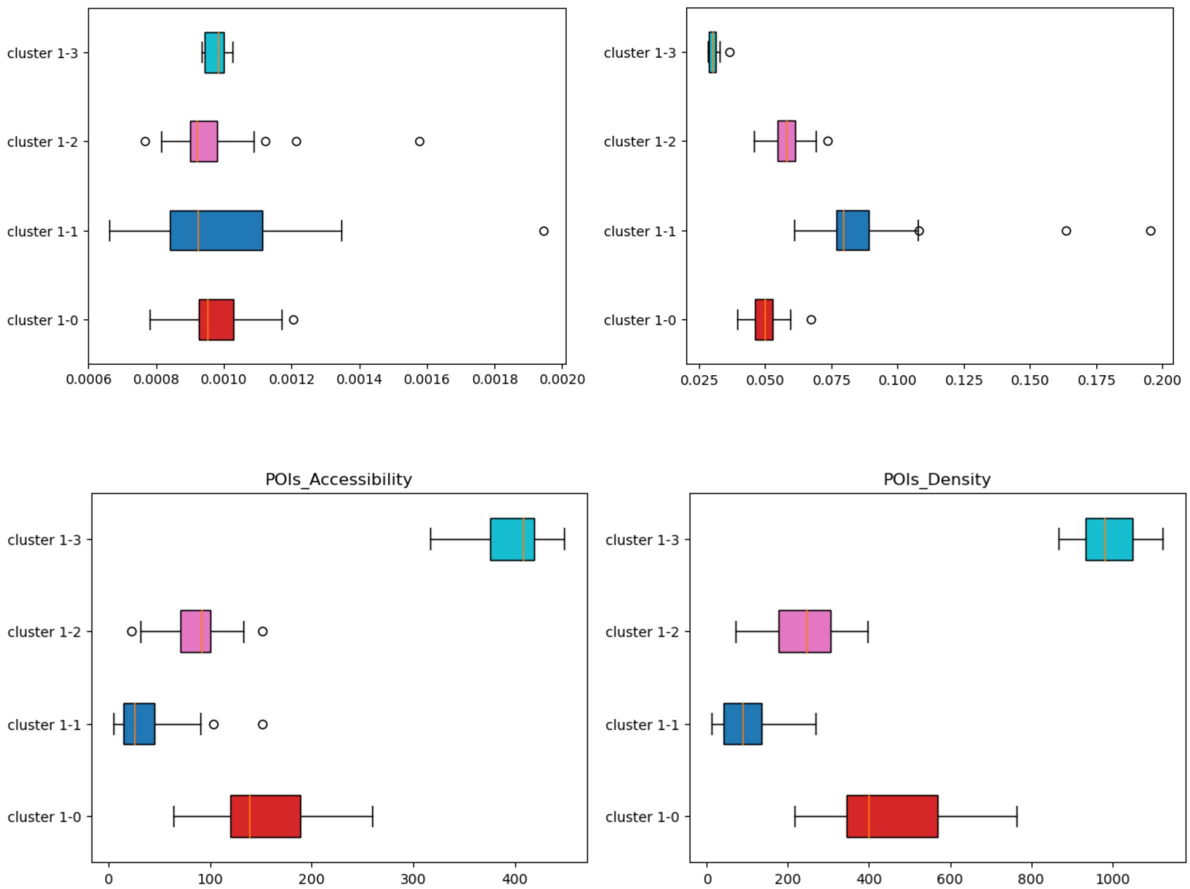


Figure 6.4 Statistical distribution of the characteristics of each sub-cluster in Node-Value-cluster-1.



cluster 1-3
cluster 1-2
cluster 1-1
cluster 1-0
0.0006
0.0008
0.0010
0.0012
0.0014
0.0016
0.0018
0.0020
0.025
0.050
0.075
0.100
0.125
0.150
0.175
0.200
POIs_Accessibility
0
100
200
300
400
POIs_Density
0
200
400
600
800
1000

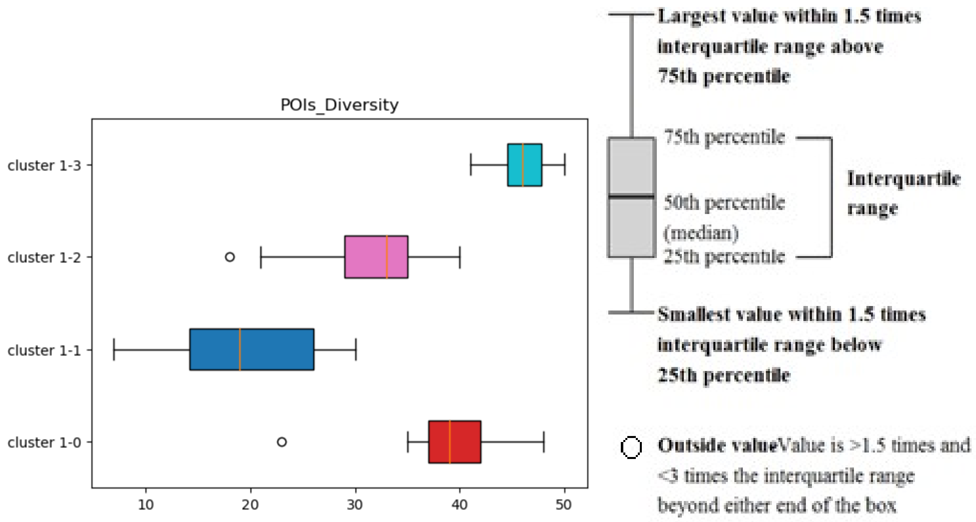


Figure 6.4 (continued) Statistical distribution of the characteristics of each sub-cluster in Node-Value-cluster-1.

1.1.iii) Node-Value-cluster 2

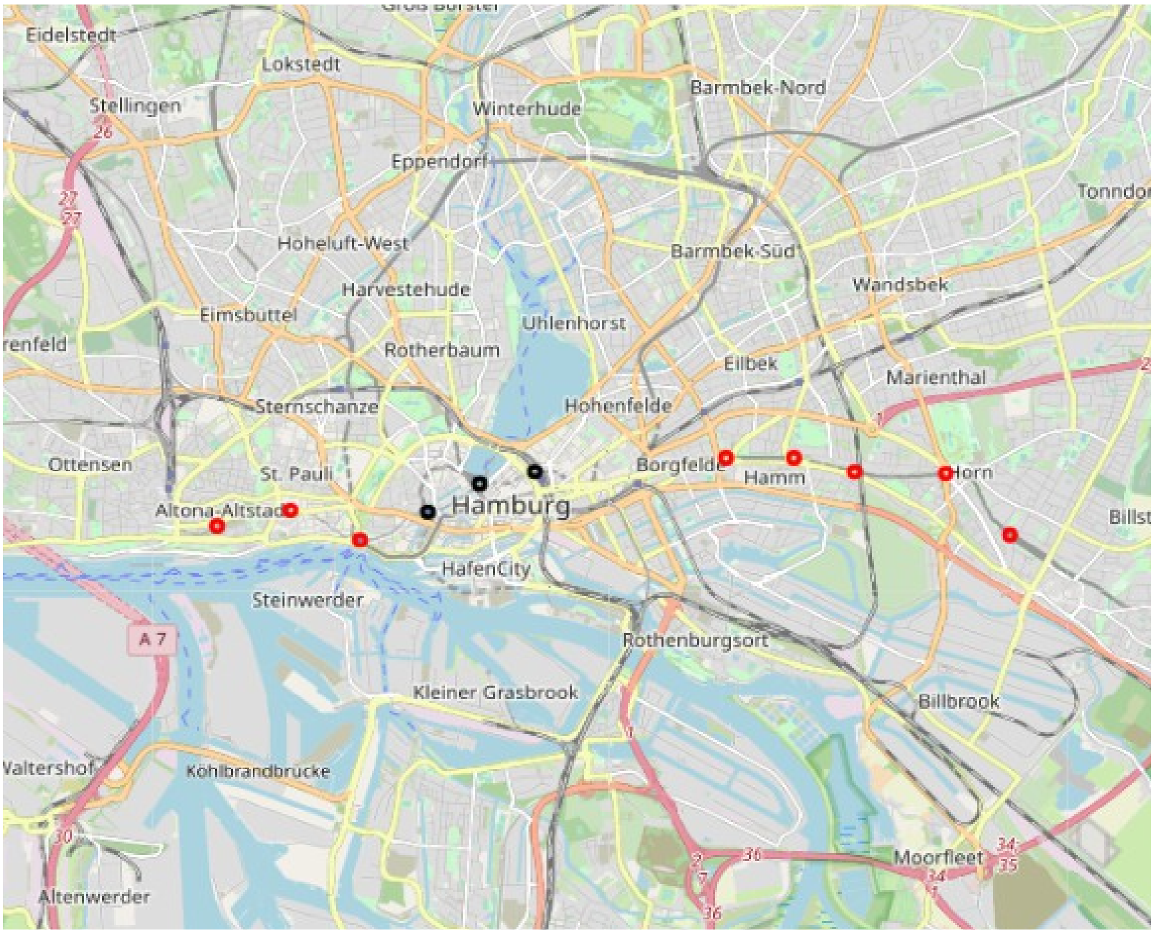


Figure 6.5 Spatial distribution of each sub-cluster in Node-Value-cluster-2.

The spatial distribution of the three sub-clusters in Node-Value-cluster-2 is mapped in Figure 6.5. In chapter 3 we have learned that, compared to other clusters, stations in Node-Value-cluster-2 are mostly distributed in the inner city and has the highest Node Value. After further dividing the cluster into 2 sub-clusters based on their Place Values, the results show that stations of

- Cluster 2-0 are mainly distributed in the inner and middle suburbs.
- Cluster 2-1 are predominantly located in the inner city.

Next, the sub-clusters can be characterized by the statistical distribution of the indicators. Based on the criteria we set up in Table 6.1, the results in Table 6.9 and Figure 6.6 show that cluster 2-1 has the highest Place Value because it has the highest value in terms of the number of nodes, number of links, average Node Degree and entropy of street bearing. Also, it has the lowest value of average segment length and Betweenness Centrality. This group of station also has highest value in terms of accessibility, density and diversity of POI. By contrary, cluster 2-0 has the lowest Place Value among the Node-Value-cluster-2.

In sum, with regard to Place Value, cluster 2-1 > cluster 2-0.

Table 6.9 Descriptive statistics of each sub-cluster in Node-Value cluster 2.

	All station in cluster 2		Cluster 2-0		Cluster 2-1	
	mean	std	**mean**	std	**mean**	std
Number of nodes	**307.45**	154.02	**223.38**	54.78	**531.67**	66.56
Number of links	**707.18**	400.52	**488.13**	128.51	**1291.33**	201.22
Average Node Degree	**4.49**	0.29	**4.36**	0.19	**4.85**	0.15
Average segment length	**79.12**	19.44	**87.21**	16.16	**57.55**	3.90
Entropy of street bearing	**6.17**	0.45	**5.93**	0.19	**6.81**	0.10
Average Clustering Coefficient	**0.08**	0.02	**0.08**	0.02	**0.08**	0.01
Average Closeness Centrality	**0.00092**	0.00012	**0.00090**	0.00013	**0.00099**	0.00004
Average Betweenness Centrality	**0.048**	0.014	**0.055**	0.010	**0.031**	0.003
POI_Accessibility	**196.10**	133.95	**127.62**	71.24	**378.71**	56.31
POI_Density	**492.09**	325.07	**322.75**	174.19	**943.67**	39.51
POI_Diversity	**38.45**	7.65	**35.25**	6.20	**47.00**	2.65

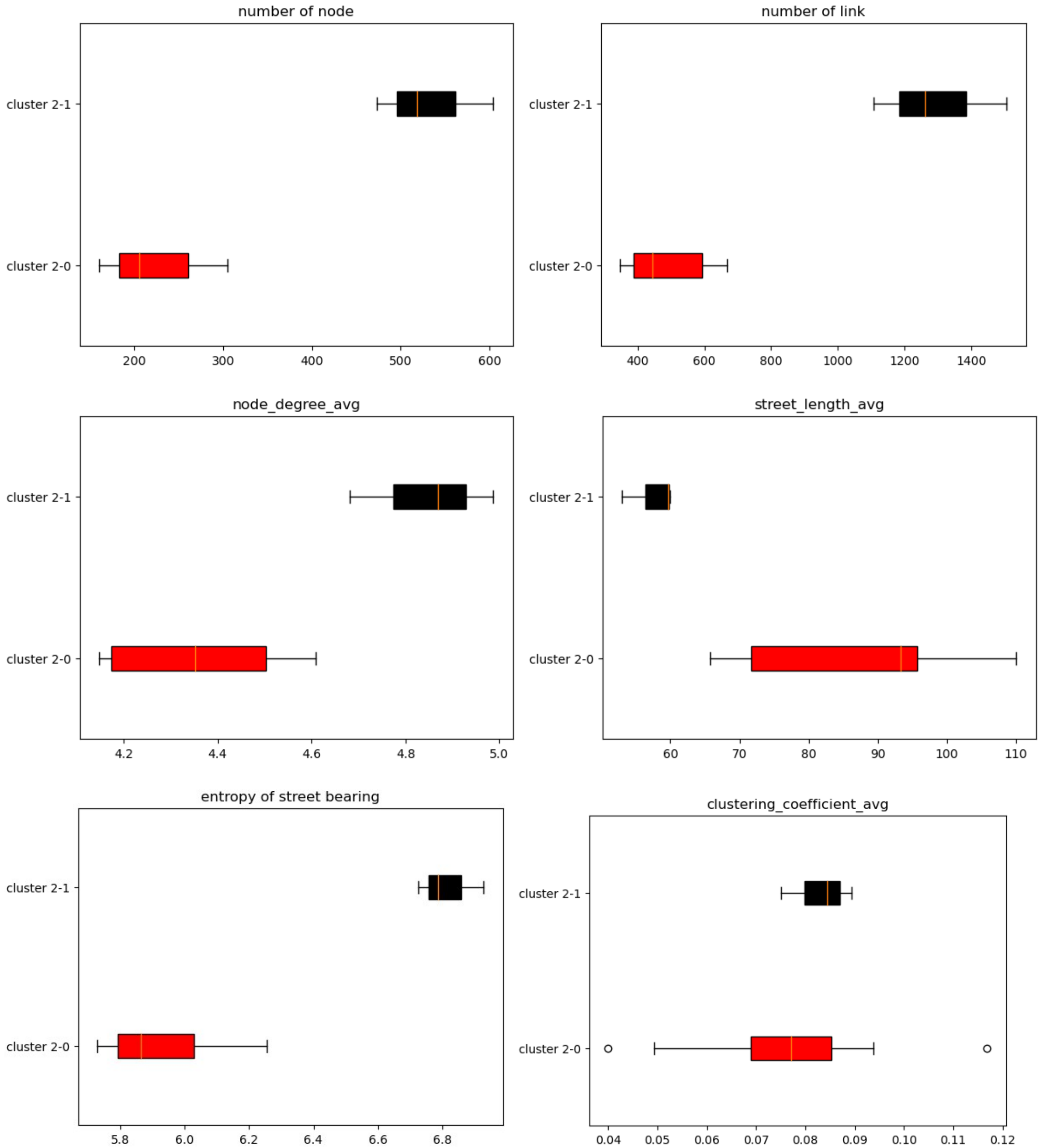
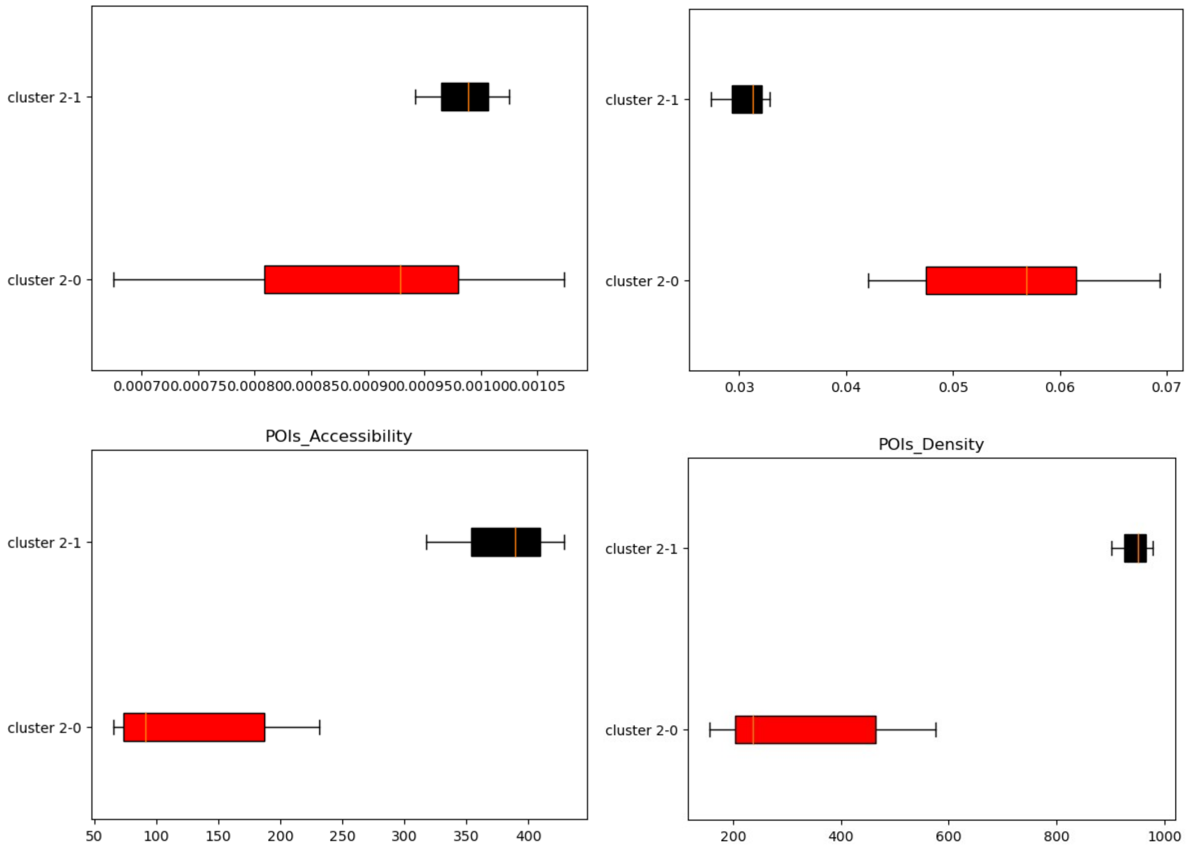


Figure 6.6 Statistical distribution of the characteristics of each sub-cluster in Node-Value-cluster-2.


cluster 2-1
cluster 2-0
0.000700.000750.000800.000850.000900.000950.001000.00105
cluster 2-1
cluster 2-0
0.03
0.04
0.05
0.06
0.07
POIs_Accessibility
cluster 2-1
cluster 2-0
50
100
150
200
250
300
350
400
POIs_Density
cluster 2-1
cluster 2-0
200
400
600
800
1000

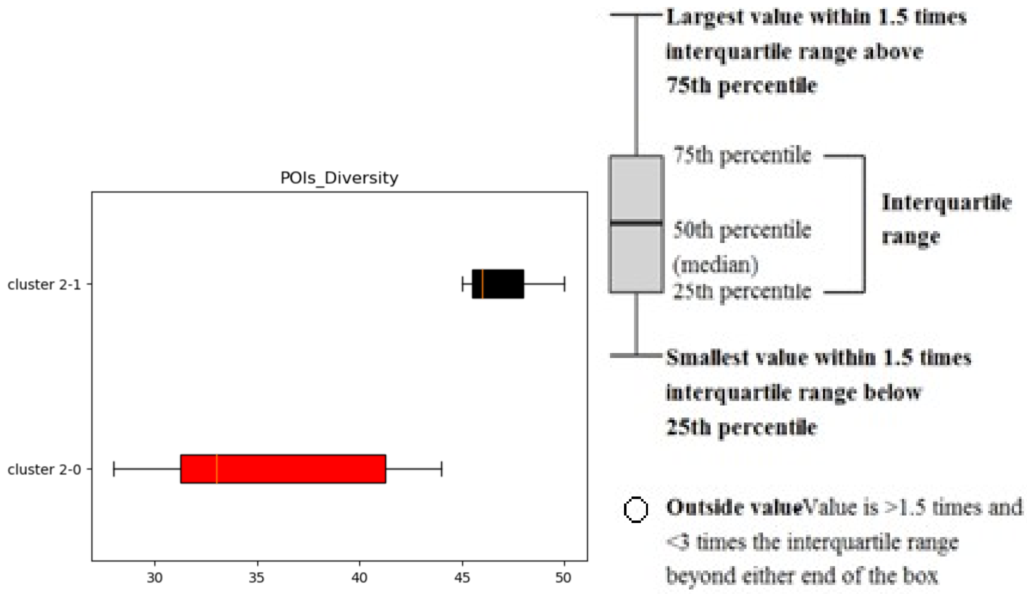


Figure 6.6(continue) Statistical distribution of the characteristics of each group in Node-Value-cluster-2.

4. Conclusion and discussion

At the beginning of this chapter, we have set up two tasks as the goals. The first goal is to further divide the stations into sub-clusters based on their Place Values, which are measured by two categories of indicators: network analysis and the accessibility, diversity and density of the POI. Affinity Propagation is used to group the neighborhoods around the train stations in order to determine their Place Value in the Node-Place Model.

After each station is assigned with both the Node and the Place Values, it will be possible to construct the Node-Place Model, as shown in Figure 6.7. The stations can then be compared and ranked by both the Node- and Place-Values. Note that, Figure 6.7 is merely an attempt to relate our results to the Node-Place Model proposed by Bertolini (1999). The values and distance between the clusters are depicted not in absolute but only in relative terms. For instance, the relative position means that cluster 1-2 has lower Node Value than cluster 1-0 and higher Place Value than cluster 0-2.

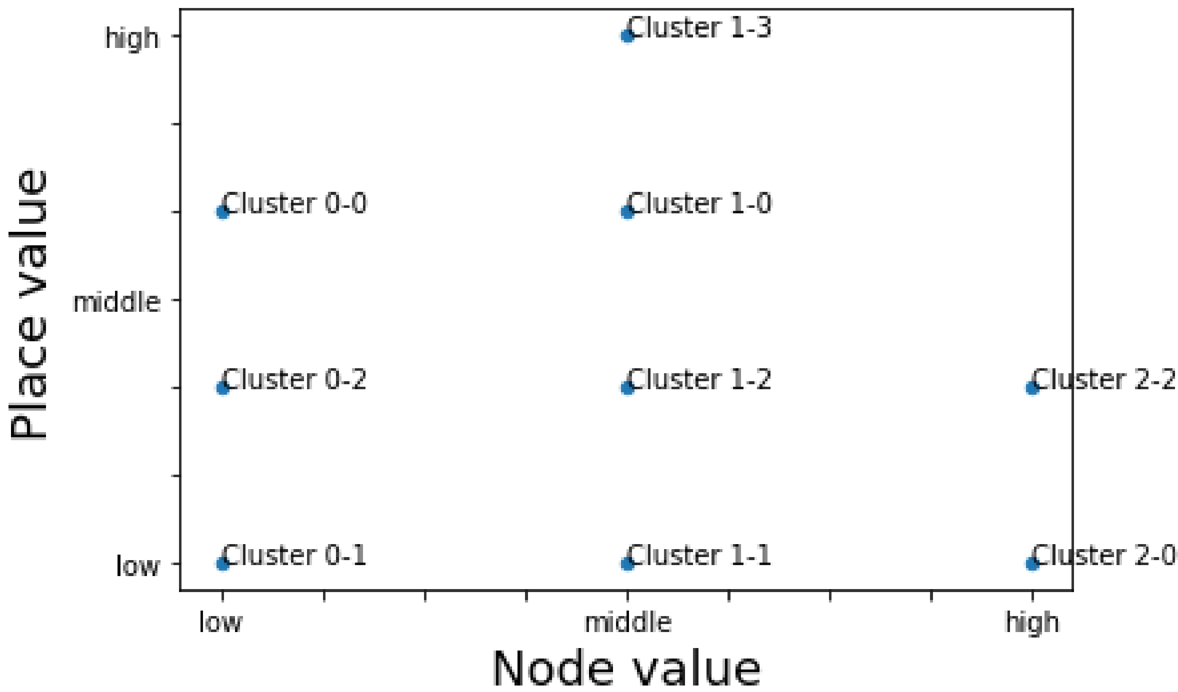


Figure 6.7 Node-Place Model of the HVV railway public transport (RPT) stations.

The results help to identify the neighborhoods that are already successful from the TOD point of view and, on the other hand, the neighborhoods with the potential for further improvement. The values of indicators can be used to indicate the direction for improvement in each sub-cluster.

The other goal of this chapter is to select stations that can be the exemplar of each sub-cluster so that, in the following chapter, we can zoom into the catchment area around the station and scrutinize the detailed spatial distribution of the street network and POI.

Based on the results of network analysis and POI-related indicators, the selected exemplars and the order of their Place Values are:

- Überseequartier (cluster 0-0) > Großhansdorf (cluster 0-2) > Pinneberg (cluster 0-1)
- Steinstraße (cluster 1-3) >Berliner Tor (cluster 1-0)>Klosterstern (cluster 1-2) >Klein Flottbek (Botanischer Garten) (cluster 1-1)
- Hauptbahnhof Nord (cluster 2-1) >Hammer Kirche (cluster 2-0).

In addition, by comparing and Table 6.7, Table 6.8, Table 6.9, one interesting pattern emerges that the high-Node-Value cluster, i.e. cluster 2, also performs better in the measurements of Place Value. For example, comparing to cluster 0 and 1, cluster 2 has the highest average number of nodes, average number of links and average value of the POI-related indicators, i.e. density, diversity and accessibility of POI.

Finally, as mentioned in section 6.2, it should be noted that the correlations between indicators in this chapter is only based on the case of Hamburg. In the future, it would be interesting to compare these correlations among cities with different spatial configuration. In fact, this comparison can also be carried out among TOD neighborhoods in the future studies.