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SPACE SYNTAX ANALYSIS INTEGRATING STREET AND RAILWAY NETWORKS:
A case study in Tokyo

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Abstract

This study utilizes digital map data for the GIS and aims to develop a model that integrates railways with the street and road network to analyze citywide spatial configuration by the space syntax model. Combining street data and railway data, we present a spatial analysis method that considers the reality of travel in urban areas: multi-modal travel. Proposed method enables us to analyze the space syntax of different modes by "travel time." We analyzed the spatial configuration by three characteristics: accessible number of places, mean travel time, and betweenness. For number of accessible places and length of mean access time, characteristics of the areas in Tokyo were revealed and a certain level of possibility of analysis was confirmed.

Keywords: *public transport, multi-modal networks, Access time*

Theme: *Modelling and Methodology Developments*

1. Introduction

Given the clear link between human activity and the configuration of urban space, many researches have examined the exact nature of this dynamic relationship, and various models have been developed. In the area of transportation and marketing science, such models include the gravity model, the Huff model and the logit model. Various variant models have been developed and applied to real planning schemes. Despite the large crossover areas of focus, urban studies use different models, such as those based on space syntax and graph theory. Among those models, many recent researches have focused on segment analysis of space syntax, the emphasis being largely due to the prevalence of geographic information systems (GISs). Some GIS data of railways, streets, and roads comprise nodes and edges (links) so that users may build a network by themselves. By using such data, anyone can build a segment map for space syntax very easily. This study utilizes such digital map data for the GIS and aims to develop a model that integrates railways with the street and road network to analyze citywide spatial configuration by the space syntax model. Combining street data and railway data, we present a spatial analysis method that considers the reality of travel in urban areas: multi-modal travel.

Using GIS data and the presented method enables us to integrate and analyze the space syntax of different modes by "travel time."

2. A Unified Segment Map

For the analysis of large area, GIS data has high usability. After the research of angular analysis and segment analysis carried out by Jiang (2001), Dalton et al. (2003), Hillier and Iida (2005), Turner (2007), the effectiveness of such analysis was confirmed, and it became easier to manipulate GIS data for conducting space syntax analyses. Recently, many researchers have used GIS data for analyzing street and road networks.

There are a few challenges to including railway networks in the space syntax community. Law et al. (2005) analyzed railway networks and demonstrated significant correlation with the number of travelers at stations. Nes and Stolk (2012) analyzed the road and street network in Holland and discussed the types and locations of stations with respect to the street and road network. Gil (2012) presented a method to combine public transport routes and streets networks. This work built up detailed connections between two networks, public transport and the street network in London, and analyzed them.

In this study, we used railway data and street and road data from the 1/25000 digital map published by Geospatial Information Authority of Japan (GSI). In the dataset, there are street and road polylines, which have the attributes of various properties including widths and classes. In addition, it includes railway data comprising polylines for both stations and railways between stations.

By creating additional links, we have connected stations of different lines whose locations are very close with each other, enabling people to transfer between different lines. In addition, we connected stations and nodes of several streets or roads in the vicinity of eligible stations. Thus, we built up the whole of Tokyo's 23 wards together with its surrounding area.

Figure 1: Tokyo Special District of 23 wards (right: a part of Jonan area)

3. Syntax Analysis by Travel Time

In order to analyze this unified network, this study uses the metric of travel time needed to reach other places. For the railway network, average travel time between stations can be calculated by referring to timetable data. From the average travel time between stations, the common average speed of the train on each line was calculated. As for the road and street network, a pedestrians' speed can be assumed to be about 80 m/min. Car speed can be assumed considering the width of each street and road and its posted speed limits. In this study, we include only pedestrian and public transport because of several reasons, such as the time for calculation. Our aim was not to provide a full-scale comprehensive model but to determine the feasibility of the methodology.

Although pedestrians travel on foot, after they arrive at the station and get on train, they can move very rapidly. They can also change lines at junctions. Some stations are also linked by short walkway links, so some travel between stations does not occur using the rail network. After arriving at the goal station, rail passengers become pedestrians again as they walk to their destination. Travel time from origin to destination is measured by incrementing the time to pass each link considering the speed on each link.

Thus, as a measurement, neither minimum angular depth, minimum step depth, nor minimum metric depth, but minimum time length (depth) between different places is used in this study. We suppose that people (pedestrian) move at a speed of 80 m/min; trains move at the speed calculated as per the timetable, i.e., about 500 m/min to 1000 m/min; and travelers walk between transit stations using inter-station walkways at 80 m/min.

4. A Case Study in Tokyo's 23 Wards

The target area of this study is Tokyo district, composed of 23 wards, with a population of about 13 million (compared with 33 million people within the Tokyo metropolitan area). More precisely, a buffer area of 3 km around the 23 wards was added in order to reduce the edge effect, because marginal area does not have enough surrounding places for the analysis if buffered area were not added. Throughout the world, Tokyo is ranked as a city with extremely high- developed public transport networks. According to the person trip survey conducted by the government within the Tokyo metropolitan area in 2008, 90% of trips inside these 23 wards were made by public transport such as train and subway. Only 10% of trips involved the use of automobiles. Hence, the setting in this study covers about 90% of the travel undertaken in this area.

We determined three indices for the analysis: number of accessible places, mean access time, and betweenness. Accessible number of place is the sum of accessible places within a certain length of time when he or she departs from a place to others on the network. Mean access time is the arithmetic mean time from a place to other places that are accessible within a certain length of time. Betweenness is the index of the amount of paths who pass the place, determined on the basis that there are uniform trips between all places which are connected within a certain length of time and travelers are rational actors selecting optimal paths offering minimum travel times.

Maximum travel time length, which corresponds to a so-called “radius,” is set as 15, 30, 60, and 90 min. A local sub-network accessible from a place is defined at each place, and the above three index values are calculated within each sub-network.

Analysis of the network was conducted by using the original software developed by the authors using c language. The program loads the unified network of ESRI shape format, builds adjacent data structures, calculates minimum time paths to a node in the sub-network by a tuned-up Dijkstra method, and calculates indices for each place. As the network consists of 180 thousand nodes and 160 thousand edges, it needs large amounts of time to process the data. The global calculation took about 10 days to process.

5. Results

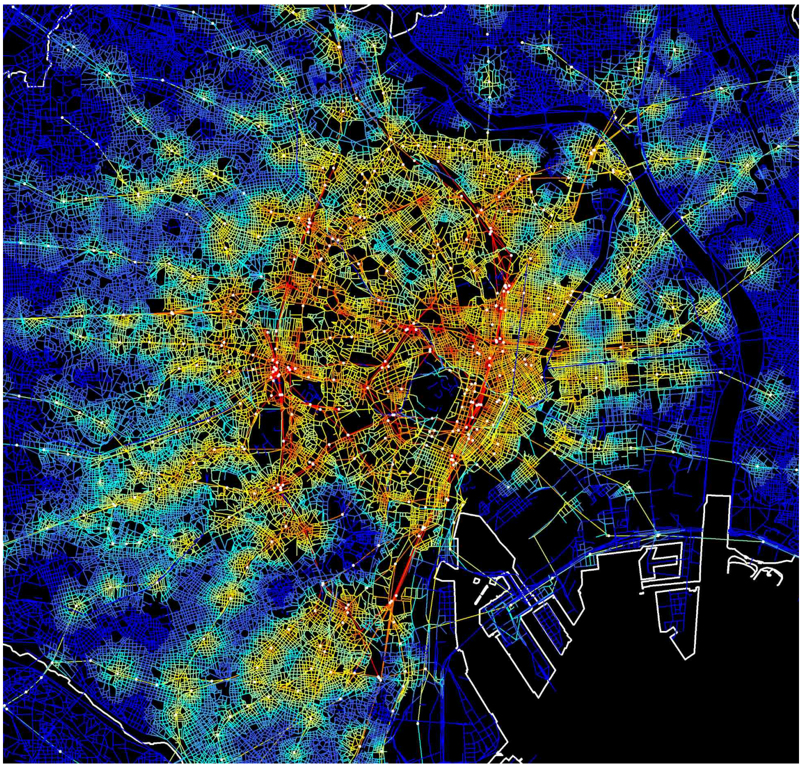
Initially, the result of the analysis within 30-min local accessible area is shown (Figure 2). Further, 30-min travel will amount to about 2 km on foot and about 20 km by train. In Japan, 30 min is regarded as the near- upper limit of commuting time in the general provincial city. However, in the Tokyo metropolitan area, 30 min is not such a long time because many people spend more than 1–2 h in their commute every day. It takes a longer time period to travel within Tokyo; it is not so short a time period that people cannot put up with in their everyday life, in Tokyo metropolitan area.

Figure 2a shows the number of accessible places within 30-min travel. The places having high counts are those accessible from many places. At the central area of Tokyo and at around every railway stations, we can see the high number of accessible places. We can easily assume that many business and commercial land use will concentrate on such places. Figure 2b is a photograph of night Tokyo taken by an astronaut from space, and Figure 2c is the distribution of retail shops in this area based on telephone address book data. Comparing these three figures, we can see common characteristics of the distribution of the places where accessibility is high, be full of light at night, and many retail shops exist.

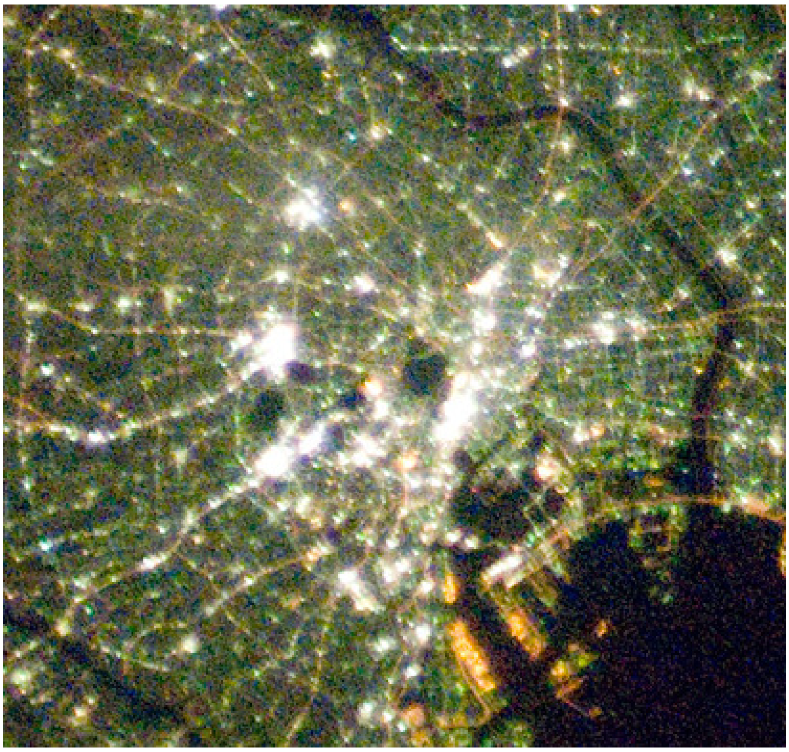
In order to examine the relation, point data of retail shops and segment data of spatial analysis were aggregated to the unit areas of smallest administrative district polygons. Figure 2d is the scatter plot diagram of the areas showing the correlation of the number of retail shops counted by telephone address book data and number of accessible places within 30 minutes. Correlation coefficient between the two variables is 0.466, therefore there isn’t strong correlation between them. However, seeing the figure, we can recognize that the district where many retail shops locate has relatively larger number of accessible places within 30 minutes, because almost all points of rightward are at the upper side of graph plane; the plots look like a right triangle shape, whose right angle is at the upper left of the graph plane. We presume that, since there are many residential districts of high accessibility in the central area of Tokyo, the points of leftward side of the plane are spreading.

The map of mean access time length is shown in Figure 2e. Mean access time is lower in the Shitamachi area, the traditional downtown of Tokyo. In contrast, at the city center area of Yamanote, which is the traditional residential district of the samurai class, mean access time is relatively high. It is also relatively higher than in suburban residential areas of Tokyo, which were developed in 20th century. Therefore, it can be concluded that the Yamanote area is relatively isolated within the neighbourhood but more connnected with many relatively-distant places. In the Yamanote area, there will be more access from distant places than from its neighbourhood.

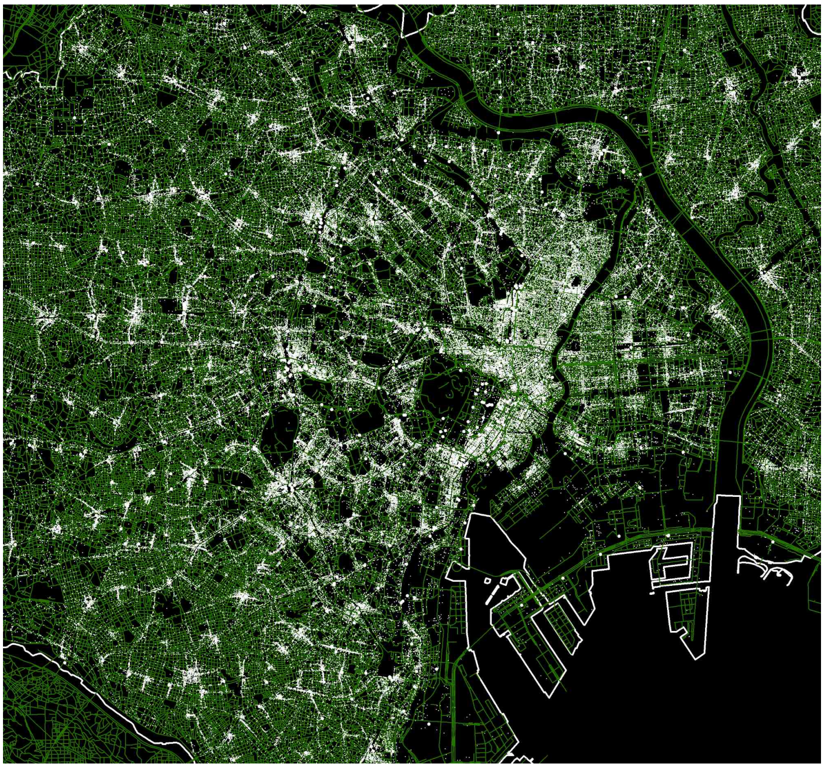
In suburban residential areas as well as at some areas distant from railway stations, there are some island-shaped blue areas. These areas have low accessibility within 30 min because of local low accessibility to railway stations and sparse streets and roads. However, in general, access time is lower around almost all railway stations. Although the trend is clearer at the stations in centeral Tokyo area, even suburban areas show remarkably low access times in the close vicinity of stations. Access times are quite different according to whether they are close to railway stations or not.



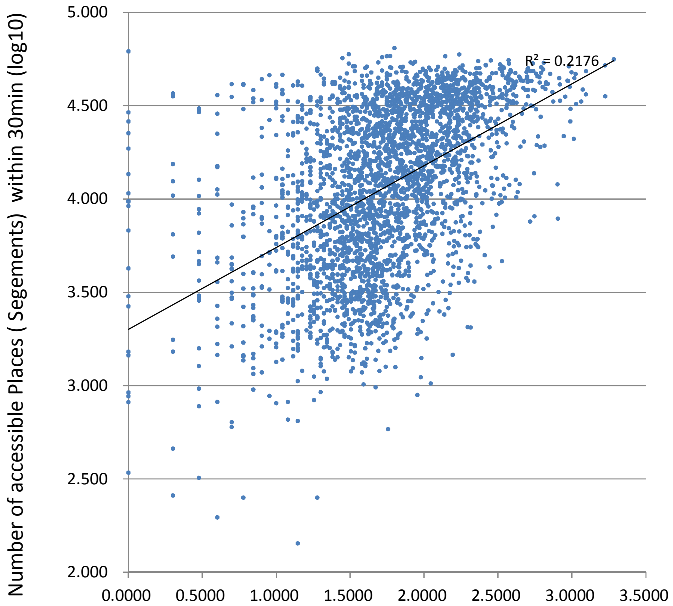
(a) Number of accessible places



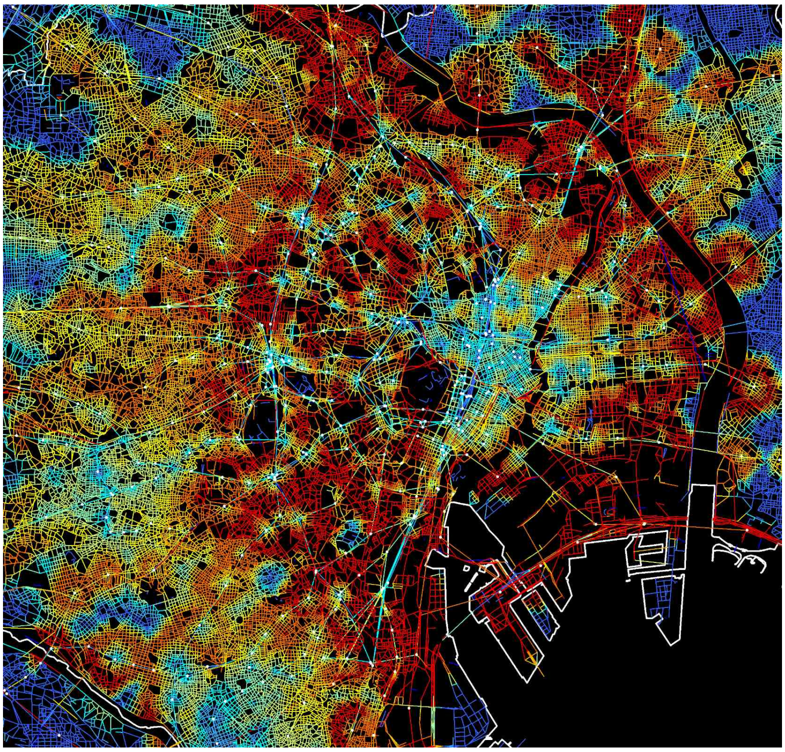
(b) Night Tokyo, as seen from space（NASA/JSC Gateway to Astronaut Photography of Earth）



(c) Distribution of Retail Shops (collected and plotted by telephone address book data)



(d) Scatter Plot Diagram of Smallest Administrative Districts (n=3,135), Tokyo 23 wards



(e) Mean access time length

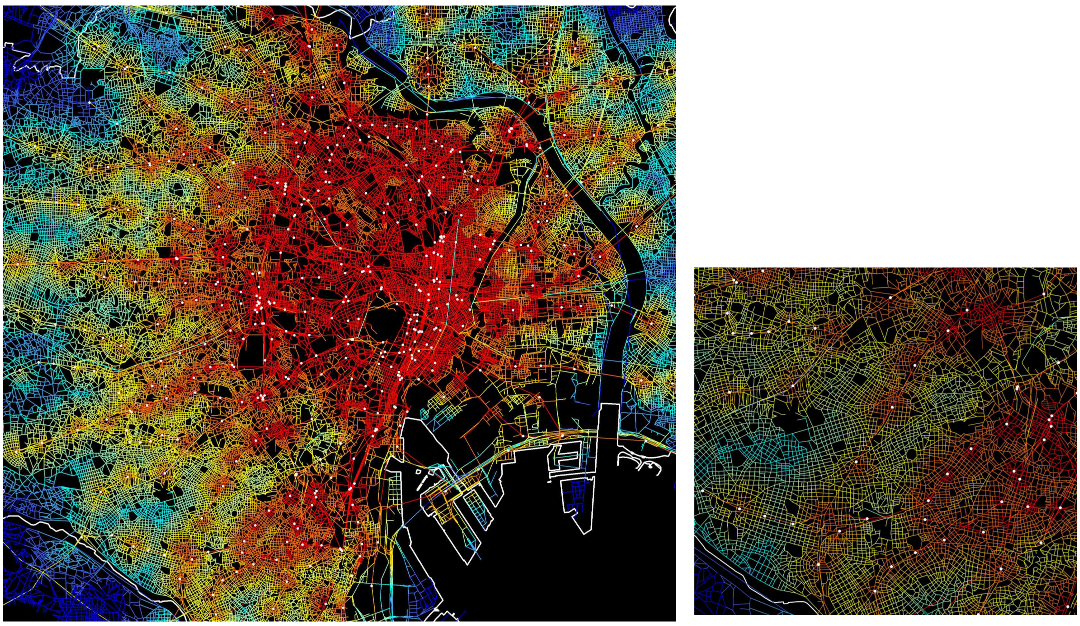
Figure 2: Analysis for within 30-min travel time length

Next, result of the analysis within 60-min travel time is presented in Figure 3. The trends at 60 min broadly align with those observed at 30 min. Further, 60 min amounts to the time in which most people can travel to the large business and commercial centers in Tokyo from most any residential district in Tokyo's 23 wards. Although 60-min travel time will not connect all residential districts with each other, it will connect most business and commercial centers with most residential districts.

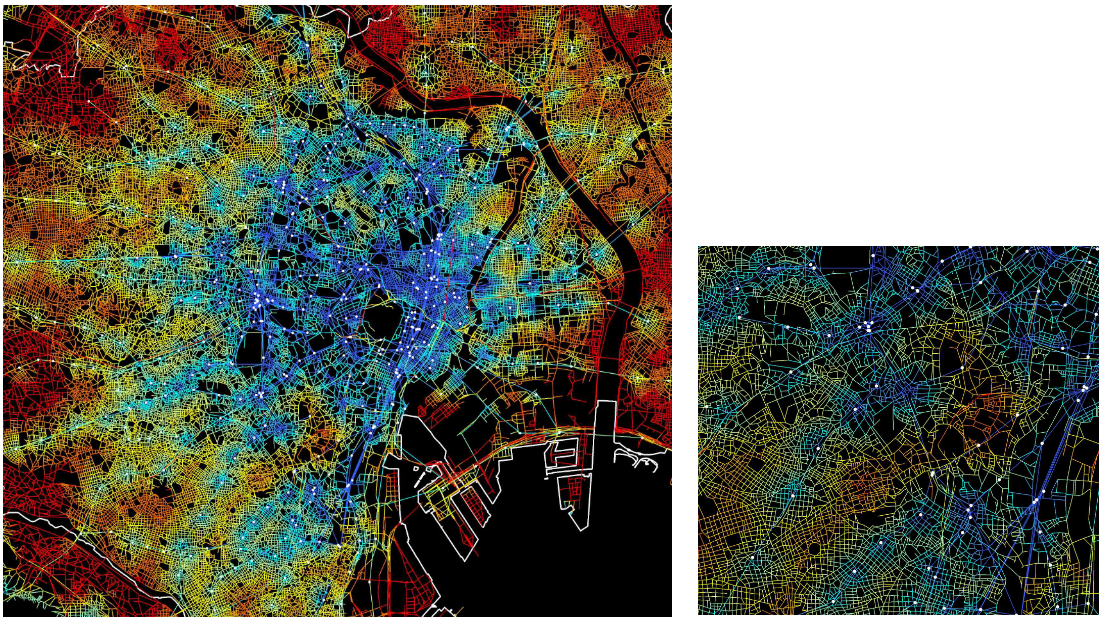
The number of accessible place is higher in the central Tokyo and decreases toward the suburbs, in general. In addition, it decreases as distance from railway station increases. The location having the highest number of accessible places is Tokyo station. From Tokyo station (or to Tokyo station), more than 80% of places in 23 wards are accessible. One area, which is called Jonan (south of castle), was enlarged and it is exhibited in the Figure 3a right. There are both suburban residential districts and local commercial centers in this area. It is clearly shown that number of accessible places is higher around the local rail station. But the gradation of color is rather low and blurry, revealing that the difference in the number of accessible place inside the local area is relatively smaller than in the case of 30 min.

As for mean access time, it is lower at central Tokyo, and higher in the suburbs. Yamanote area changed to deep blue from dark red. In central Tokyo, mean time length is about 30 min, but at the most inconvenient place in suburban area, it totals more than 50 min. Thus, the central area has greater advantage considering the long time (distance) trip.

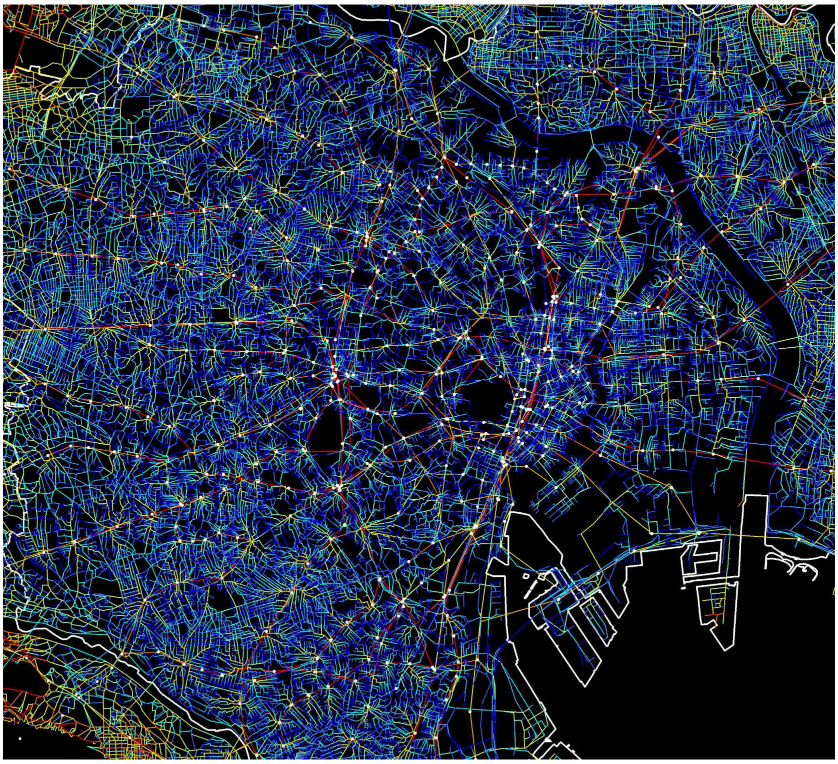
Next, betweenness by time is calculated and presented in Figures 3c. These figures show the logarithm of betweenness. We can see the flows from stations to deep areas, which look like "capillary blood vessels" arranged radially from each local station. However, the value of the betweeness is did not vary widely between all stations in Tokyo's 23 wards (See Figure 3d and 3e). In fact, real human flows are dense in central Tokyo and sparse in suburban areas. This inconsistency arises from the setting we made, that the trips from origin to destination are uniform in all area. In reality, there are strong flows of commuters from residential areas to central areas and a high commuter flow between business districts for business activities. It will be necessary to consider these characteristic flows in further studies.



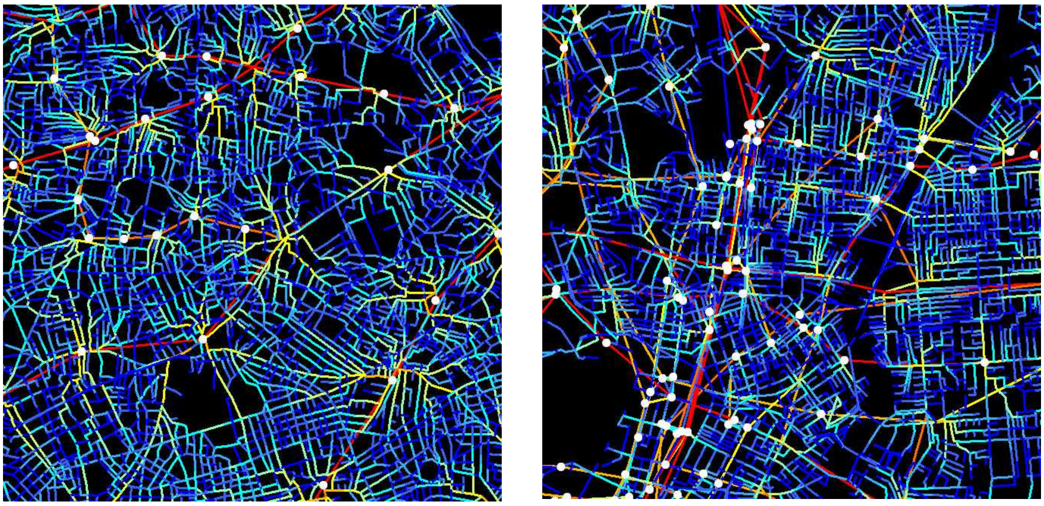
(a) Number of accessible places



(b) Mean access time length



(c) betweenness (log)



(d) Suburban area (Setagaya) (e) Central area

Figure 3: Analysis for within 60-min travel distance

6. Discussion and Conclusion

This study built up a unified transit map composed of both railway network and the street and road network and proposed the analysis of spatial configuration by travel time. We analyzed the spatial configuration according to three characteristics: accessible number of places, mean travel time, and betweenness. For number of accessible places and length of mean access time, characteristics of the areas in Tokyo were revealed and a certain level of possibility of analysis was confirmed. We demonstrated the feasibility and utility of such analysis via a case study of Tokyo's 23 wards. As for betweenness, the hypothesis that there are uniform trips seems to be too strong and unrealistic. More realistic settings should be taken into account.

In the further studies, analysis by travel time of other travel modes will be necessary. Bicycles, buses, private cars etc., are a few of the travel modes for possible inclusion. If we combine the use of bus routes, railways network, and street and roads network, we will be able to analyze further aspect of the network. Furthermore, if we consider probable speeds of movements on streets and roads by cars, we will be able to analyze another aspect of networks by travel time. Interrelated analysis of multi-modes could be explored.

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