Walking Behavior and Neighborhood Environment:
A Case Study in Tokyo Metropolitan Area

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Abstract

Walking is an activity that most people engage in and it is the simplest way for majority of people to go about their daily life. Walking behavior is important in both the aspects of personal health and urban mobility. Generally, walking behavior can broadly be categorized into three types: occupational, recreational and utilitarian walking. Among all the three categories, recreational and utilitarian walking are frequently compared with neighborhood environment. The affecting factors of neighborhood environment on these two categories are also different since recreational walking is more impulsive while utilitarian walking is more compulsive.

Walking time is usually used as the value to quantify the degree of walking behavior. In this study, the People Flow Data of Tokyo in 2008 was used for acquiring walking time of residents in Tokyo Metropolitan Area (TMA) and the total number of samples in this dataset reached 576,806. The People Flow Data is a data set processed by Center for Spatial Information Science (CSIS), the University of Tokyo based on the Person Trip Survey Data created by the Ministry of Land, Infrastructure, Transport and Tourism of Japan for monitoring dynamic changes in daily people flow, which provides the individual locations in every minute within 24 hours. A total number of 13 attributes were included in each record for individuals.

In recent years, with the development of GIS (Geographical Information Systems) as well as the growing amount of available spatial data, studies on neighborhood environment with objective data analyzed by GIS software is becoming popular. GIS provides spatial measures of particular environmental attributes in local areas. The

adoption of GIS makes it possible to measure indices of walkability at the local level in cities or regional areas with readily available data for the purposes of evaluating new environmental and policy initiatives to encourage walking.

The purpose of this study is to detect the characteristics of people's walking behavior with the questionnaire-based People Flow Data of Tokyo Metropolitan Area and evaluate the neighborhood environment of these people to find potential relationships between people's walking behavior and the physical attributes of their neighborhood environment.

The spatial patterns of residents' average total walking time (TWT), utilitarian walking time (UWT) and recreational walking time (RWT) were revealed from the People Flow Data. In general, the spatial patterns of these three categories all showed consistency with the urban structure of TMA. Residents living in the 23 special wards of Tokyo as well as the Yokohama city had higher TWT, UWT and RWT. The railway lines showed a potential contribution to the amount of UWT but no contribution to the amount of RWT. People living in rural areas had the lowest walking time regardless of the walking types. This result revealed that people in rural areas of TMA relied much more on vehicles than people in urban and suburban areas of TMA.

When focusing on the effects of personal attributes, men had more walking time than women regardless of the walking purpose. However, the difference didn't have any spatial patterns when allocating the walking time into the map. Age difference was more obvious when separating all the people into groups of adolescence, labor force and retirees. The results showed that labor force had higher UWT and retirees had higher RWT. It was reasonable since labor force spent more time on the way of going to and going back from working places which were included in utilitarian walking while retirees had the most sparing time for their recreational activity which included recreational walking. The difference in occupation could also result in the difference of walking behavior. Similar to the findings from comparing different age groups, white-collar workers and high school students had the highest UWT as they took a lot of utilitarian walking during their way to and back from working places or schools. On the other hand, No-occupation people and housewives had the highest RWT as they had the longest sparing time during weekdays.

The results of evaluating utilitarian and recreational walkability had a consistency with the result of residents' utilitarian walking time and recreational walking time derived from the People Flow Data. This consistency proved that residential density, street connectivity, land use diversity, bus stop density, railway station accessibility are necessary factors for evaluating utilitarian walkability and street connectivity, greenness density, and parks density are necessary for evaluating recreational walkability in TMA.

Besides the findings of the associations, this study also released the maps of eight neighborhood attributes related to walking behavior, utilitarian walkability, recreational walkability, average walking time in TMA. These maps showed the spatial patterns similar to the urban structure. Previous studies mostly concentrated on a micro scale, but the findings here showed a possibility of comparing the neighborhood environment from the perspective of the whole urban structure.

The originalities of this study mainly came from the separation of walking behavior based on the purpose and the method to handle People Flow Data and the neighborhood environment-related data. Considering the big amount of the People Flow Data, the findings in this study could be more trustful. In addition, the widely-separated spatial location of the samples provided the possibility to link the walking and walkability patterns with the urban structure, which was a very rare approach that could not be found in previous studies in this field. The other originality is the buffer analysis based on individuals. Unlike the common approach which evaluates the neighborhood environment first and then assigns the value to the points fallen into each area, this study created a 1 km buffer from individuals' residence and define this buffer as the neighborhood context. With this approach, the scale of each person's neighborhood could be more accurate and it increased the possibility to find trustful relationships between neighborhood environment and walking behavior.

Another point need to be concluded is the comparative study between two different types of walking behavior. Unlike most of the studies in this field, the author employed two sets of criteria for evaluating effects of neighborhood environment on utilitarian walking and recreational walking respectively. When detecting the effect of personal attributes, the analysis was also separated into the two categories of walking. The results in this study proved the value of studying effects of personal attributes as well as neighborhood environments separately based on the type of the walking behavior. This comparative study approach was strongly recommended by the author to be applied into other related studies.

Keywords: Neighborhood Environment; Personal Attributes; Recreational Walking; Tokyo Metropolitan Area; Utilitarian Walking; Walkability.

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List of Abbreviations

BSD	Bus stops density
CSIS	Center for Spatial Information Science
CHS	Community Health Survey
GD	Greenness density
GIS	Geographical Information System
LUD	Land use diversity
NDVI	Normalized Difference Vegetation Index
NEWS	Neighborhood Environment Walkability Survey
PD	Parks Density
PEDS	Pedestrian Environment Data Scan
RD	Residential density
RSA	Railway stations accessibility
RWT	Recreational Walking Time
SC	Street Connectivity
SSA	Sightseeing Spots Accessibility
SPSS	Statistical Package for the Social Sciences
TMA	Tokyo Metropolitan Area
TMG	Tokyo Metropolitan Government
TWT	Total Walking Time
UWT	Utilitarian Walking Time

Chapter 1

Introduction

1.1 Background and problem statement

Fast development in transport technology has brought great convenience to people's daily life, especially for those who live in highly urbanized areas. However, the convenience in daily life caused a significant proportion of people all over the world adopted a physically inactive lifestyle (Van Dyck et al., 2013). World public health recommendations emphasize the benefits of engaging in at least 150 min of moderate-intensity aerobic physical activity most days of the week, or at least 75 min of vigorous-intensity aerobic physical activity throughout the week (Chen et al., 2013). In this context, around 50% of the population in America were found to be physically inactive (Hallal et al., 2012) and the proportion of inactive adults in Australia even reached 57% (Wang et al., 2016). Besides the high proportion, the trend of an increase in the proportion of physically inactive people was also noticed. In Japan, the proportion of adults achieving 10,000 steps per day fell by 5% from 2000 to 2007 (Inoue et al., 2011). The evidence in China showed that the average physical activity level of Chinese adults decreased by more than 30% from 1999 to 2006 (Ng et al., 2009). Physical inactivity was found to be linked with higher risks of overweight and obesity. Besides, physical inactive lifestyles affect people's mental health as it can increase the mental pressure and cause depression (Wang et al., 2016). On the other hand, physically active lifestyle is widely recommended for preventing diseases including coronary heart disease, type 2 diabetes, some cancers, clinical depression, or other chronic disorders (WHO, 2013). Physical activity also contributes to increased strength, flexibility, endurance and bone density (Edwards and Tsouros, 2006). In addition, some forms of physical activity can enhance the relationship between family members and friends. As a result, the promotion of physical activity is attracting high attention and becoming a health priority in recent years (Heath et al., 2012).

Physical activity is defined as any bodily movement produced by skeletal muscle that results in energy expenditure and includes a wide range of activities, such as walking, exercise, swimming, dancing (Koohsari et al., 2013). Among all the physical activities, walking is recognized as one of the most common, accessible, inexpensive forms of physical activity and is an important component of total physical activity in adult populations (Hallal et al., 2012). Walking is an activity that most people engaged in and it is the simplest way for the majority of people to go about their daily life. Several reasons contributed to the popularity of walking. Firstly, walking is suitable for people in all the age groups as it doesn't require any specific skills or space. In comparison, some other popular physical activities, such as soccer, tennis, swimming, require both basic skills and a specialized area for the activities. Secondly, walking is flexible. It allows people to choose their own favorite movement intensity and time. Some people prefer jogging in the morning while some other people choose to take a walk in the late afternoon after working. Nowadays, it is even common to find people jogging in the midnight. Thirdly, walking can also help people, especially those from the low-income groups, to be away from inactive lifestyles as it can easily be accomplished without cost on buying any equipment or renting any site.

Despite the health outcomes and popularity, walking is also important in the aspect of urban mobility (Lamíquiz and López-Domínguez, 2015). Increasing attention has been attracted on walking as it is a fundamental part of urban mobility and it has the potential to deal with the big issues in urban studies such as improving the urban sustainability in environment, enhancing access to public transport, reducing the burden of transport costs on the family budget, preventing health problems by promoting active transportation and recovering the urban quality of cities.

From the evidences and statements mentioned above, it is reasonable to say that knowledge on how to promote people's daily walking behavior is critical. Generally, walking behavior can broadly be categorized into three types: occupational, recreational and utilitarian walking. Occupational walking refers to those accomplished in someone's working time. Many jobs need employees to walk during the working time. For instance, policeman needs to go on patrol, postman needs to send mails to each residence, and waiter and waitress in the restaurant need to walk to serve the dishes. This kind of walking is strongly determined by the content of each person's job and it is difficult to be related with the neighborhood environment. Recreational walking refers to those undertaken in someone's leisure time without a determined destination, such as taking a walk in a park, running along the track or walking a dog. Recreational walking is strongly affected by personal attributes since people in different age, gender and occupation have a different amount of spare time. Usually, compared with young and mid-aged people, old people have more spare time to enjoy recreational walking. And in Japan, since many women choose to be a housewife after marriage, they have more time and chance to walk during their daily life. In addition, people who have a job with low pressure and confirmed working hours intend to have more spare time and it increases the potential of these people to take a walk during a day. Recreational walking is also related with neighborhood environment since people prefer to enjoy recreational walking in places with plenty of greenness, no noise, good sightseeing spots and no dangers. Utilitarian walking refers to walking with a destination for further behavior. Utilitarian walking always has a specific destination and the walking is regarded as mobile means similar to riding a bicycle, taking a bus or driving a car. As a peculiar form of mobility, it does not simply rely on dedicated infrastructures such as the pavements and crossings, but is also highly related to the built environment (Krizek et al., 2009). In this context, utilitarian walking is related to accessibility to potential destinations. There is a high potential for people to choose walk as the moving means if there are plenty of facilities for daily life around the neighborhood which are accessible by walking.

Among all the three categories, recreational and utilitarian walking are frequently compared with the neighborhood environment (Saelens and Handy, 2008). Considering only the physical attributes of the environment, utilitarian walking behavior tends to have a stronger relationship with the neighborhood environment compared to recreational walking behavior (Lee and Moudon, 2006). The affecting factors of the neighborhood environment on these two categories are also different since recreational walking is more impulsive while utilitarian walking is more compulsive.

Walking time is usually used as the value to quantify the degree of walking behavior. Most of these studies relied on the self-reported questionnaire. Collecting questionnaires requires both time and manpower. Besides studies done by a big group or the government, others are force to be done within a small spatial coverage so that the number of questionnaires can be reduced. However, the small study area and small amount of samples can create incidental results which were hard to be duplicated even in the same area. As a result, there is a big demand in this field to have a data sharing system which can provide self-reported data accomplished by thousands or even millions of people to make it possible to do researches in a municipal-level or country-level.

With the popularity of researches on detecting the potential effect of the neighborhood environment on walking behavior, the term “walkability” was created as an index to evaluate the friendliness of the environment to walking. There is no formal recognition of the word ‘walkability’ in either the Oxford or Cambridge dictionaries. Because of the unclear definition, there is no standard principle to follow when measuring walkability. In general, researchers choose a variety of elements to measure walkability and the elements are decided based on the study areas and targets. Key elements of a neighborhood with a high walkability are high street connectivity, high land use mix and high residential density (Leslie et al., 2007). These elements can be assessed by both subjective data of neighborhood and objective data from both observational measuring and open public data sources. Other elements include accessibility to potential destinations, greenness, aesthetics, safety, existence of sidewalks, traffic volume, etc. (Day, 2016).

Studies on evaluating neighborhood environment started with the adoption of perceived data gaining from questionnaires. One of the most widely used questionnaires is the NEWS (Neighborhood Environment Walkability Survey) developed in 2002. The questionnaire-based data is easy to be analyzed but the collecting process is both time and money consuming. As a result, most of these studies were taken place in a neighborhood level scale and the findings are not reliable to be applied to other study areas because of the uncertainty of both the neighborhood attributes and the residents’ attributes. The reliance on self-reported data has limitations because the bias of individuals who answer the questionnaires can cause the inaccuracy of the data. As a result, it is common to find inconsistent results from different studies.

In recent years, with the development of GIS (Geographical Information Systems) as well as the growing amount of available spatial data, studies on neighborhood environment with objective data analyzed by GIS software is becoming popular. GIS provides spatial measures of particular environmental attributes in local areas. The adoption of GIS makes it possible to measure indices of walkability at the local level in cities or regional areas with readily available data for the purposes of evaluating new environmental and policy initiatives to encourage walking (Leslie et al., 2006). The approach based on available spatial data and GIS software can reduce the time and cost in collecting data. Nowadays, the popularity of data sharing makes it easy to obtain city-level spatial data of the world. Besides, GIS software provides the function to visualize and analyze the data from the spatial view, including the capacity of mapping, spatial analysis and modeling (Leslie et al., 2007). These advantages provide a possibility to evaluate the neighborhood environment on a large scale (such as a municipality level) and compare the results with the spatial patterns of the urban structure and the public transportation system.

However, the adoption of GIS and objective spatial data has brought several challenges. First, spatial data from different sources may differ in format, coordinate system, definition of attributes, resolution, scale, etc. All of these differences need to be unified according to the study area. The process of unification may require simulation of some mismatched or missing data. Second, huge data often includes plenty of information. However, a specific study only needs a small part of the whole database. As a result, the extraction of useful information (known as "data mining") is a necessary step during the data handling and this step requires knowledge of the structure of the whole data. Third, analyzing big data requires great computing power. Computer and software have limitations in the maximum amount of records and the maximum data size. In this case, the data need to be divided according to the limitation of computing power and processed separately. Although these challenges exist, using GIS and objective spatial data in neighborhood environmental studies is attractive as it provides different views and understandings in this field (McGinn et al., 2007).

In summary, studies on patterns of daily walking behavior and characteristics of proper neighborhood environment for promoting walking is important and more attentions should be paid on this field because of the benefits in both personal health and urban mobility. However, big issues still existed in this field because of the uncertainty of both the original data and the evaluation method. With the development of data sharing and the utilization of GIS, more findings in this field will be detected and researchers, as well as urban planners, are able to get more accurate knowledge on how to build a walkable neighborhood.

1.2 Review of previous studies

The focus of this study was on finding the characteristics of walking behavior and detecting the potential effects of neighborhood environment on the walking behavior. Before addressing the content, there is a need to clearly define the terms used in this research to prevent misunderstanding of the work. Then the main points of these studies were automatically departed into two parts: analyzing the walking behavior and evaluating the neighborhood environment.

A brief review of literature related to the concepts and definitions of the related terms, studies on walking behavior and neighborhood environment is presented in the following sections.

1.2.1 Concepts and definitions of the terms

There are several terms related to this study that are not clearly defined. Before the description of the content, a brief review of literature for these words is necessary to get a better understanding of this thesis. The terms discussed in this chapter include utilitarian walking, recreational walking, and walkability.

Utilitarian walking is one category among all the walking behavior. According to Hekler et al. (2012), utilitarian walking was defined as "walking for the primary purpose of accomplishing errands or getting somewhere." Examples included walking to work or another venue, parking farther away from a destination, and walking while at work rather than emailing, telephoning, or faxing coworkers or peers. They found that "having to go to multiple locations daily and traveling greater distances to locations were associated with engagement in more utilitarian walking." In another study, utilitarian walking was defined as "walking for specific purposes such as travel to work or school (Hajna et al., 2015)." They measured the walkability of the neighborhood and found no association between walkability and total walking time. However, they detected a positive graded relationship between walkability and utilitarian walking time. Saelens and Handy (2008) simply defined utilitarian walking as "walking to reach a destination." They gave a review of the papers discussing the correlation between built environment and walking. Scott et al. (2009) evaluated the level of utilitarian walking by asking respondents on how many days in a week they engaged in walking to work or to school, to a store or to do an errand, to the bus or to a neighbor's house that took at least 10 minutes. Beaudoin et al. (2007)

also used “10 min” as the threshold, they defined utilitarian walking behavior as walking “to work or school, to a store or to do an errand, to the bus, or to a neighbor’s house for a walk that takes at least 10 minutes.” Doescher et al. (2014) defined utilitarian walking as “walking to routine destinations” and they proved that the common factors that were considered useful in promoting utilitarian walking really worked in small towns. As a conclusion, utilitarian walking refers to walking with a purpose and a certain destination.

Recreational walking is another category of walking behavior which is often compared to utilitarian walking. Hekler et al. (2012) defined recreational walking as walking specifically for fitness, health, or physical recreation. In Sugiyama and his co-authors’ work, the threshold “10 minutes” was used for extracting recreational walking (Sugiyama et al., 2013). They evaluated the level of recreational walking by asking the targets “during the last 7 days, on how many days did you walk for at least 10 minutes at a time in your leisure time.” Spinney et al. (2012) defined recreational walking as “walking, hiking, and jogging” activities that may occur at any location, including parks, trails, and even shopping malls. In summary, there are two definitions for recreational walking. The difference in definition came from the difference of key element. If considering the purpose, recreational walking refers to walking for fitness, health, or entertainment. On the other hand, if time is the key element, recreational walking is defined as the walking behavior happened in someone’s leisure time.

The word ‘walkability’ is used by many streetscape designers and advocates of walking for health and recreation. Yet, the origins of the term and the meaning of the concept are not clear. The variation in definitions of walkability indicated an inconsistency when comparing findings in different researches. In a report from Mayor of London, Walkability was defined as the extent to which walking is readily available to the consumer as a safe, connected, accessible and pleasant activity (Mayor of London, 2004). This definition is from the perspective of urban planners. By contrast, Abley (2005) defined walkability as "the extent to which the built environment is friendly to the presence of people living, shopping, visiting, enjoying or spending time in this area." This definition emphasizes more on the subjective feeling of residents. Gebel et al. (2009) explained walkability as an index to measure how friendly the area is to pedestrians. This simple definition showed the key element, pedestrians, when talking about walkability. In another research, Leslie et al. (2007) used GIS to measure walkability. And they defined this GIS-derived walkability as an index to classify the extent to which the objective physical characteristics of a local neighborhood may be conducive or not to walking behavior. In Duncan and his colleges' work, neighborhood walkability is a combination of environmental features of neighborhoods that promote various forms of physical activity (Duncan et al., 2011). In this research, they emphasized the importance of the concept 'neighborhood'. Not by chance, Marshall et al. (2015) also mentioned walkability of a neighborhood measures whether community design encourages or inhibits walking. In conclusion, walkability can be understood as an index that reflects the friendliness of the neighborhood environment to the presence of walking and normally a certain scale which is defined as the neighborhood is necessary during the process of measuring walkability.

1.2.2 Walking behavior studies

Walking behavior of individuals is different partly because of the difference in personal attributes. The difference of personal attributes includes age (De Meester et al., 2012), gender (Pelclová et al., 2013), occupation (Van Dyck et al., 2011), race (Hooker et al., 2005), driving status (Kamada et al., 2009), marital status (Lee and Moudon, 2006; Porch et al., 2015), education (Rundle et al., 2008) et al. There are plenty of studies discussing about the effects of one or several attributes mentioned above on walking.

Owen et al. (2007) assessed the walking behavior for transport and for recreation among 2,650 adults recruited from neighborhoods in an Australian city. The study design was stratified by area-level socioeconomic status, while analyses controlled for participant age, gender, individual-level socioeconomic status, and reasons for neighborhood self-selection. The findings showed that being female, having a child in the household, and having a higher household income were negatively associated with weekly frequency of walking for transport, while neighborhood walkability and neighborhood self-selection were independently positively associated.

Sallis et al. (2009) attempted to test associations between neighborhood built environment and median income to multiple health outcomes and examine whether associations are similar to low- and high-income groups. According to their results, neighborhood income was not related to any measure of physical activity. However, there was one significant interaction between neighborhood walkability and income, indicating walkability had a stronger positive association with walking for transport in high-income than in low-income participants. Based on the findings, they suggested that policies promoting walkable development patterns should be combined with other policies, such as policies to reduce local traffic congestion and air pollution, to avoid negative outcomes, especially among low-income populations.

Hanibuchi et al. (2011) selected age, gender, marital status, educational attainment, household equalized income, working status and self-rated health as the variable of individuals. However, this research didn’t discuss too much about the different patterns of walking behavior among different groups of people. This study focused on the physical activity of older adults and the main finding was that some characteristics of the neighborhood built environment may facilitate leisure time sports activity, but not increase the total walking time for Japanese older adults.

Chen et al. (2013) aimed to clarify the association between neighborhood environment and walking time across gender, age, and employment status. They collected 7,515 questionnaires in January 2007. Multiple logistic analysis was conducted to examine the associations between neighborhood environment and walking time across gender, age, and employment status: 20-39 (young-employed), 40-59 (middle-employed), and 60-79 (old-employed or old-unemployed) after adjustment for age and means of transportation. According to the results, they found that the middle-aged and old-aged female residents' walking behaviors were more influenced by their neighborhood environment.

Azmi et al. (2013) addressed that walkability could be measured through the accessibility of urban residents to retail and community facilities. They used four variables to measure residents' perception on accessibility. The four variables were the length of stay, gender, age and household income. Among all the variables, household income was highly associated with perceptions on accessibility. The other three variables didn't show significant association with the perceptions on accessibility.

Freeman et al. (2013) made an effort to detect the relationships between neighborhood walkability and active travel which included walking and cycling. From 8,064 respondents to the New York City 2003 Community Health Survey (CHS), they detected that the relationship between the built environment and active travel vary across strata of race and socioeconomic status (gender, age, education, poverty, marital status, nativity status and employment status).

Ding et al. (2014) paid attention to whether driving status of older adults affected their walking behavior. In this study, neighborhood environments were measured by geographic information systems and validated questionnaires. Driving status was defined on the basis of a driver's license, car ownership, and feeling comfortable to drive. Outcome variables included accelerometer-based physical activity and self-reported transport and leisure walking. Multilevel generalized linear regression was used for the analysis. According to the results, they found that for leisure walking (recreational walking), almost all environmental attributes were positive and significant among driving older adults but not among non-driving older adults. The findings suggested that driving status was likely to moderate the association between neighborhood environments and older adults' leisure walking.

Ghani et al. (2016) tried to analyze the gender and age differences in walking for transport and recreation. This study used data from the HABITAT multilevel study, with 7,866 participants aged 42–68 years in 2009 living in 200 neighborhoods in Brisbane, Australia. The results showed that neighborhood exposures had a different impact on the walking behavior of men and women, and young and old. They made a conclusion that relationships between genders and walking, and age and walking, were not the same in all neighborhoods, suggesting that neighborhood-level factors differentially influence the walking behaviors of men and women and younger and older persons. They suggested that identifying these factors should be a priority for future research.

1.2.3 Studies on evaluation of neighborhood environment

Besides the effect of personal attributes on walking mentioned in the previous chapter, neighborhood environment is another key element that affects people's walking behavior. Normally in this field, walkability is used as the term to describe the evaluation result of the neighborhood environment for walking. In recent years, a number of studies have revealed the relationships between walkability and walking behavior. The evaluation criteria differed between different studies. Besides the three most widely used criteria (residential density, street connectivity, and land use diversity), different studies adopted different criteria such as accessibility to facilities, aesthetics, safety, greenness, land slope, traffic volume, etc. In addition, the source data for measuring walkability also differed between studies. Some of the studies in this field adopted questionnaire-based perceived data while others use GIS-based objective data for the measurement.

Handy et al. (2002) made a review of the study in this field in 2002. They listed six criteria as the dimension of the neighborhood environment. These criteria were density and intensity, land use mix, street connectivity, street scale, athletics qualities and regional structure. They pointed out the data for evaluating these criteria can be derived from a variety of local sources, such as property tax records, building permit records, aerial photos, and street and sidewalk inventories. They also suggested GIS for the management of objective data. However, they mentioned that in 2002, the interrelationship between the built environment and human behavior was still unclear.

Leslie et al. (2005) tried to detect the consistency between the perceived data and objective data for evaluating neighborhood environment. They chose only three indices (intersection density, dwelling density and land-use mix) for measuring walkability and gave a score ranged from 1 to 10 for all of the indices. After the measurement, they categorized study area into high-walkable and low-walkable neighborhoods. Then questionnaire-based survey about neighborhood environment was done to gain the perceived data of residents in different neighborhoods. The results showed that Residents of the high-walkable neighborhood rated relevant attributes of residential density, land-use mix and street connectivity, consistently higher than did residents of the low-walkable neighborhood.

Oakes et al. (2007) used only dwelling density and street connectivity for the evaluation of walkability. However, they separated all the walking behavior into travel walking and leisure walking and detect the potential relationships respectively. They found that although neither density nor street connectivity were meaningfully related to overall mean miles walked per day, dense areas promote travel walking while large-block (less connected) areas promote leisure walking.

Glazier et al. (2012) selected four main factors (population density, dwelling density, availability of all retail and services, street connectivity) as the urban walkability index for Toronto. The results showed that the walkability index was validated against measures related to physical activity. Index values had positive associations with walking, cycling and public transit use and inverse associations with car ownership and driving trips.

Pentella (2009) had five neighborhood-scale indicators for the evaluation of walkability by the GIS-based objective measurement: residential density, street connectivity, public transit, land use mix, and crime density. Otherwise, the author used another approach named Pedestrian Environment Data Scan (PEDS) audit to evaluate the neighborhood environment from the perspectives of path condition including segment intersections, slope, crossing aids, articulation in building designs and bus stops. This step was accomplished by collecting questionnaires. When comparing the two results, the author found the two approaches didn’t produce similar walkability scores. PEDS measurement revealed a significant correlation between walkability and social-economic status, while the GIS-based approach did not. In conclusion, the author suggested more efforts on finding reliable measures of neighborhood walkability.

Inoue et al. (2010) detected the association between perceived neighborhood environment and walking among adults in 4 cities in Japan. The data was perceived data from questionnaires collecting from local residents. Questions about eight neighborhood environmental factors including residential density, land use mix–diversity, land use mix–access, street connectivity, walking and cycling facilities, aesthetics, traffic safety, and crime safety were listed in the questionnaire. According to their results, the association between neighborhood environment and walking differed by walking purpose. The results were generally consistent with previous studies that residents in high walkability area intended to walk more. However for recreational walking of women, high residential density and good land use mix–diversity had negative effects.

Sundquist et al. (2011) objectively measured the neighborhood walkability by GIS methods. An index consisting of residential density, street connectivity, and land use mix was constructed to define 32 highly and less walkable neighborhoods in Stockholm City. Then they compared the results with the walking behavior of 2,269 adults derived from questionnaires for detecting the association between physical activity and objectively measured attributes of the neighborhood environment. The findings of this study showed a positive association between objective neighborhood walkability and physical activity outcomes in a Swedish context. However, the objective assessment of the individuals' level of physical activity showed a limited difference between individuals living in highly walkable and less walkable neighborhoods. Therefore, they recommended further studies on improving the confidence of the measuring approach.

Carlson et al. (2015) focused on investigating relations of walking, bicycling and vehicle time to neighborhood walkability and total physical activity in youth. The method for measuring walkability was GIS-based by setting a 1-km street network buffer to obtain built environment features inside the buffer. The features for measuring walkability included net residential density, intersection density, retail density and entertainment density. After calculation, they classified study area into high or low walkability area and compared the results with self-reported data about physical activity from 690 adolescents. The comparison results revealed that for adolescents, walking and bicycling were positively associated with home neighborhood walkability, particularly intersection density, and residential density components. With the findings, they suggested promoting walking in youth through improving neighborhood walkability.

Jun and Hur (2015) examined how both physical and perceived walkability is associated with neighborhood social environment. The walkability was measured with four variables: net residential density, retail floor area ratio, intersection density and land use mix. Their results showed that while perceived walkability generally had a positive effect on neighborhood social environment, physical walkability is negatively related to neighborhood social environment. With the ‘unusual’ results, they suggested that there should be a reconfiguration of the dimensions of walkability because the physical environmental measures used for the walkability index nowadays were rather broad and functional.

Lamíquiz et al. (2015) focused on detecting the effects of neighborhood environment only on walking at the neighborhood scale. Data based on a questionnaire which consists the information of each neighborhood’s street network and land use were used as the source for measuring walkability. The results supported the common hypothesis that street network and built environment factors were clearly associated with the percentage of walking in urban areas. Besides, the results proved the necessity to continue research into the street network as a distinct component of the built environment because they detected the inclusion of configurational accessibility facilitated a better understanding of the street network.

Literature shows that in this field, plenty of uncertainty still existed in definition, methodology, and selection of data sources. In addition, the walking behavior can be analyzed from a variety of perspectives considering different personal attributes. The diversity also appears in the evaluation of neighborhood environment as a different combination of factors can be adopted for calculating different categories of walking behavior. As a result, studies in this field have big potential to create original findings to help promote walking behavior and give suggestions to urban planners on how to build walkable neighborhoods.

1.3 Research aim and objectives

The purpose of this study is to detect the characteristics of people's walking behavior with the questionnaire-based People Flow Data of Tokyo Metropolitan Area and evaluate the effects of personal attributes as well as the neighborhood environment on people's walking behavior. In order to achieve the main aim, several sub-objectives were accomplished. These objectives included:

- To categorize the walking behavior based on the purpose and check the characteristics of different types of walking behavior;
- To link the walking behavior with the personal attributes by detecting the potential effects of personal attributes on walking behavior from the differences in age, gender, and occupation;

- To prove the neighborhood effect on walking behavior by examining the place where the walking usually happened and find a proper scale to define the boundary of the neighborhood from the perspective of walking;
- To evaluate the neighborhood environment by measuring the walkability of each person's neighborhood and link the result with each person's walking behavior for finding the potential relationships between them;
- To produce standard data about walking behavior and neighborhood environment in Tokyo Metropolitan Area to provide possibilities for urban planners and researchers to relate them with other social-economic data for further studies.

The main aim and sub-objectives were done as follows:

- Chapter 2: This chapter described the data and methodology used in this thesis. In the beginning, the study area was introduced. Then the data source and data management for the analysis of walking behavior were addressed. The data for evaluating neighborhood, or measuring walkability, were listed and the method for detecting neighborhood effect and measuring walkability was introduced in this chapter;
- Chapter 3: The walking behavior of residents in the study area was shown and discussed. The walking behavior was firstly analyzed without setting conditions to understand the characteristics from spatial view. Then the walking behavior was separated by the purpose in order utilitarian walking and recreational walking to get the characteristics of walking behavior with different purposes;
- Chapter 4: This chapter mainly discussed the effect of personal attributes on walking behavior. The walking behavior was separated into utilitarian and

recreational while all the samples were classified according to the personal attributes of gender, age, and occupation;

- Chapter 5: This chapter focused on the detecting the potential effects of neighborhood environment on utilitarian and recreational walking behavior. The evaluation was done by measuring walkability. According to the category of walking behavior, the measurement of walkability was divided into the measuring utilitarian and recreational walkability respectively. Multiple regression analysis was done with the utilitarian walking time and recreational walking time derived in chapter 3 to decide suitable indices for measuring utilitarian and recreational walkability. Besides, the effect of neighborhood context was also analyzed;
- Chapter 6: The findings of this study were summarized. The applicability of the methods and resources developed in this thesis and their impact for future research and practice were discussed. The limitations of the data and the method used in this study were discussed. Recommendations were made for future works.

Chapter 2

Materials and methods

2.1 Study area

The study area is known as the Tokyo Metropolitan Area (TMA) and it is located in the southern Kanto region, positioned in approximately the center of the Japanese archipelago. There are various boundaries of TMA in order to incorporate different aspects. In this study, based on the available scale of the People Flow Data, the author selected an area composed of the city of Tokyo, the prefectures of Chiba, Kanagawa and Saitama, and the southern part of Ibaraki prefecture as the coverage of TMA (Fig. 2-1). TMA is known as one of the largest metropolitan areas around the world. It covers an area of approximately 13,500 km^2 and it is the second largest single metropolitan area in the world in terms of built-up or urban function landmass at 8,547 km^2, behind only New York City (Cox, 2015). Most of the study area is a nearly flat plain with altitudes less than 70 m above sea level, except for the western mountain area (maximum elevation 2,450 m) and the flat-topped mountain areas in its southeastern and northeastern parts (maximum elevation 800 m) (Bagan and Yamagata 2012).

The population of this area reached 37.6 million in 2010, which is about 29.4% of the country's population. In particular, parts of the Tokyo city had the highest population densities in the world (Bagan and Yamagata 2012). Tokyo has the largest city economy in the world and is one of three major global centers of trade and commerce along with New York City and London. TMA is a metropolitan prefecture comprising administrative entities of special wards and municipalities. The “central” area is divided into 23 special wards with a total area of 627 km^2 and a population of 9.24 million in 2015. The 23 special-ward area is the political, economic, and cultural hub of Japan. Government offices, corporations, and commercial facilities are concentrated in the heart of Tokyo, and the transportation network is well developed (TMG, 2016). The Tokyo Metropolitan Area owns the world’s most extensive urban rail network. According to the latest data from the government, the public transportation system served more than 900 million passengers in 2014 (Bureau of General Affairs, Tokyo Metropolitan Government, 2014).

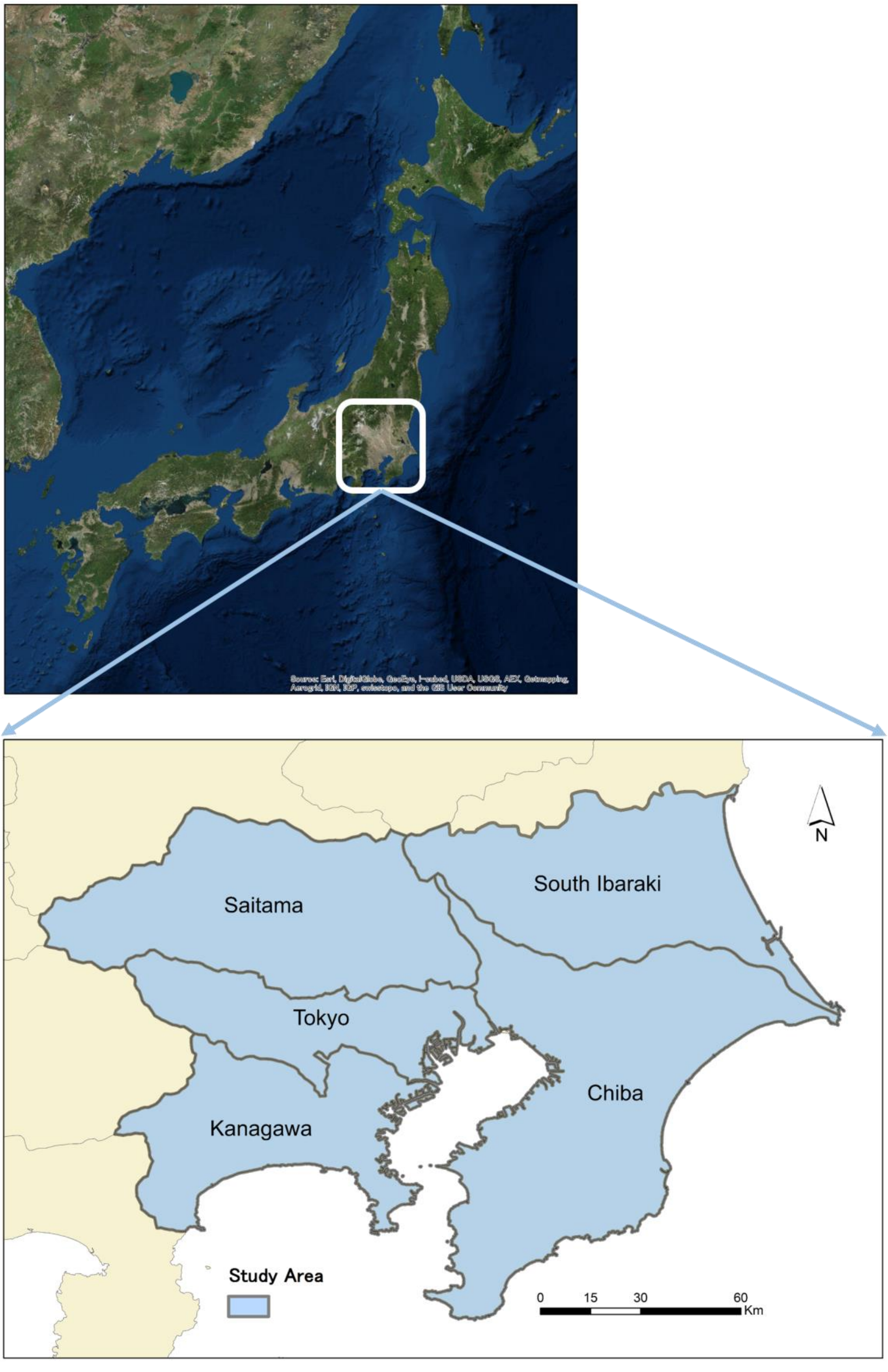

Figure 2-1: The study area: Tokyo Metropolitan Area (TMA)

2.2 Research structure

Figure 2-2 showed the flow chart of this study. The left part was the approach for detecting the characteristics of walking behavior from the perspectives of spatial and personal attributes while the right part was the process of evaluating neighborhood environment and determining the suitable criteria for calculating walkability. The combination parts were the steps for checking relationships between walking behavior and walkability.

This study started from analyzing the People Flow Data. Utilitarian walking time and recreational walking time of individuals were extracted from the People Flow Data (Pflow database) based on the purpose of each trip. Next, the utilitarian and recreational walking time were revealed by different maps separated by personal attributes including gender, age and occupation. The spatial patterns of these maps were analyzed and summarized in this step.

Following was the other part of this study. From the People Flow Data, 500 random samples were selected for detecting the effect of neighborhood environment on walking behavior. First, with the same method mentioned above, utilitarian walking time and recreational walking time were extracted separately. Then from different databases, the neighborhood environment of each individual was measured based on buffer analysis. The results were used to do multiple regression analysis by setting the walking time as the independent value. In this step, the walking behavior was also separated based on the whether it happened within the neighborhood or not. After this step, the criteria suitable for measuring utilitarian walkability and recreational walkability were determined. Later, the combinations of criteria for utilitarian walkability and recreational walkability were applied to the whole study area to create the utilitarian and recreational walkability maps.

These maps were compared with the walking time map from the perspective of urban structure. Besides this, the correlation between walkability and walking time were detected for making the final conclusion. With all the findings mentioned above, the conclusion was made.

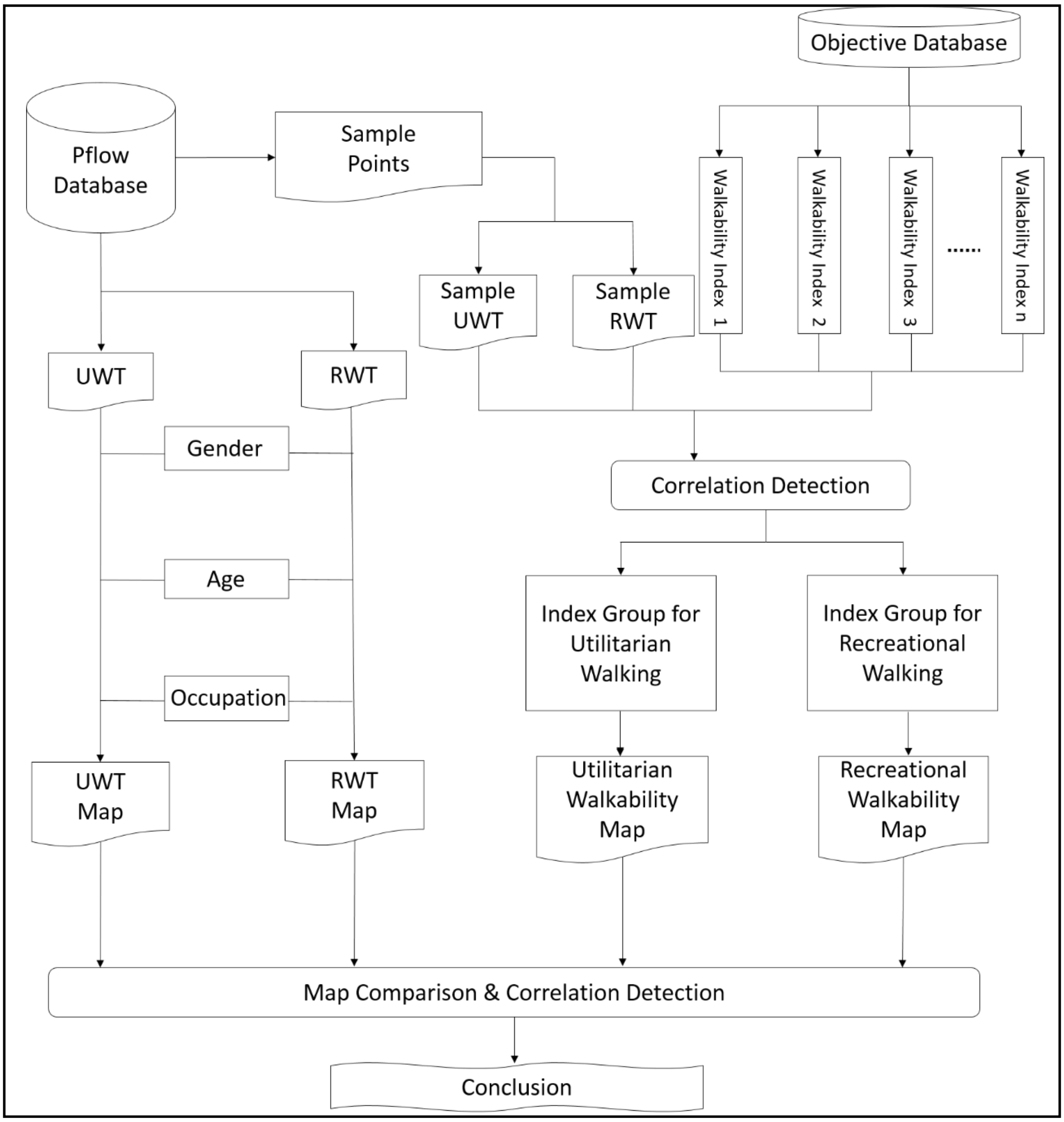

Figure 2-2: Work flow chart

2.3 People Flow Data

The People Flow Data was a data set processed by Center for Spatial Information Science (CSIS), the University of Tokyo for monitoring dynamic changes in daily people flow, which provides the individual locations in every minute within 24 hours. The data source was made from the Person Trip Survey Data created by the Ministry of Land, Infrastructure, Transport and Tourism of Japan. This survey has been done in Japan for over 40 years. These surveys originally intended to capture the macroscopic aggregated flow in each area for analyzing transportation on an urban scale. Despite the data's fragmentary nature due to the limited locations sampled (for example, residences, offices, and nearest stations), person-trip data were valuable because they documented the flow of disaggregated people on a large scale.

In order to convert Person Trip Survey Data into People Flow Data, three procedures for processing data were implemented: (a) geocoding the first and last points of sub-trips to specify spatiotemporal locations, (b) calculating the shortest route between the two locations, and (c) interpolating minute-to-minute location information based on detailed network data. Such a people-flow dataset could consist of an individual's location at each minute. Moreover, this dataset could be reconstructed from fragmentary but large-scale spatiotemporal data using sufficient infrastructure data (Sekimoto et al., 2011). The People Flow Data was supposed to be able to show an individual's location at each minute and estimate the total number, density of people at every minute because they're obtained from unbiased surveys sampling data from all ages.

In this study, the People Flow Data of Tokyo in 2008 was used for the measurement and the total number of samples in this dataset reached 576,806. Table 2-1 showed the attributes of People Flow Data with descriptions. A total number of 13 attributes were included in each record for individuals. PID was the main key of the data that record the number of each person who engaged in the survey. TNO was the trip number which records the sequence of every trip happened in one day for one person. SNO was the sub trip number that separates the trip into different parts and records the order. A whole trip could be one person went from home to the shopping mall while a sub trip refered to one part of the whole trip such as the process from home to the bus stop, from bus stop to railway station, or from railway station to the shopping mall. LON and LAT recorded the longitude and latitude of each person at each time point. The spatial information is recorded by these two attributes. GENDER, AGE, and OCCUP recorded the social-economic status of each person. ZCODE provided the spatial information of each person by OD-zone. PURPOSE recorded the purpose of each trip while TCODE gave the information of transportation mode they used for accomplishing each trip. MAGFAC and MAGFAC 2 were the adjustment factors for estimating the total number of people that each record represented.

Table 2-1: Attributes of People Flow Data

Field ID	Field Name	Description
1	PID	Unique person ID
2	TNO	Trip number
3	SNO	Sub trip number
4	LON	Longitude position
5	LAT	Latitude position
6	GENDER	Gender
7	AGE	Age group
8	ZCODE	Current location by zone code
9	OCCUP	Person occupation
10	PURPOSE	Purpose to trip
11	MAGFAC	Adjustment factor
12	MAGFAC2	Adjustment factor
13	TCODE	Mode of transportation

(Data source: CSIS, University of Tokyo)

2.4 Data management for People Flow Data

Two formats of People Flow Data, ID-based and time-based, were available. In this study, the time-based data of 3:00 a.m. was used for getting the home address of all the respondents in this survey. The reason is that 3:00 a.m. is the starting point of the survey and most people stayed at home at that time point. After getting the home address of all the people, ID-based data was used for acquiring the walking time of each person. The processing of People Flow Data included five steps:

- Record residents' home address by using time-based table of 3:00 a.m.;
- Input the ID-based table and extract the records with a query that Transportation Mode = 1 (Walk);
- Separate the extracted table into utilitarian walking table and recreational walking table by using query sentences on the purpose of the trip;
- Count all the trip records (one record one minute) by person id and extract the total walking time (TWT), utilitarian walking time (UWT) and recreational walking time (RWT) of each person in one day;
- Link the result with the 3:00 a.m. time-based table to add the attribute of home address to the ID-based extracted tables.

With the final table recorded the walking time, it is able to do analysis about the effect of personal attributes on different walking behaviors since this table also provided the personal information (age, gender, occupation) of each respondent. Table 2-2, 2-3 and 2-4 revealed the based information of these three personal attributes. In addition, since the table has the spatial information of home address, the neighborhood of each individual can be found. With the GIS software and objective spatial data, the effect of neighborhood environment on different walking behaviors can be analyzed.

Table 2-2: Gender separation in People Flow Data

Gender	Number of people	Proportion (%)
Male	274,067	47.51
Female	302,740	52.49

(Data source from: CSIS, University of Tokyo)

Table 2-3: Age separation in People Flow Data

Age	Number of people	Proportion (%)
5-10	26,119	4.53
10-15	27,584	4.78
15-20	24,884	4.31
20-25	25,542	4.43
25-30	31,003	5.37
30-35	43,473	7.54
35-40	52,482	9.10
40-45	47,693	8.27
45-50	39,963	6.93
50-55	35,896	6.22
55-60	45,382	7.87
60-65	47,507	8.24
65-70	43,014	7.46
70-75	33,976	5.89
75-	24,684	4.28

(Data source: CSIS, University of Tokyo)

Table 2-4: Occupation separation in People Flow Data

Occupation	Number of people	Proportion (%)
Agricultural/Forestry/Fishery	8,851	1.53
Labor/Factory	20,309	3.52
Sales	21,776	3.78
Service	44,000	7.63
Transport Service	11,842	2.05
Security Service	3,194	0.55
Office Worker	62,342	10.81
Professional	81,361	14.11
Manager	27,967	4.85
Other Occupation	11,038	1.91
Elementary and Junior-high Student	56,997	9.88
High School Student	14,824	2.57
College and University Student	18,163	3.15
House-wife	87,207	15.12
No-occupation	93,134	16.15
Others (Not Categorized)	948	0.16
Unknown	12,869	2.23

(Data source: CSIS, University of Tokyo)

2.5 Categorizing walking behavior

Based on the purpose of the trip, all the walking behavior was categorized into three categories: utilitarian walking, recreational walking and incidental walking. The hypothesis was that for different categories of walking, the effects of personal attributes as well as neighborhood environment differed with each other. In addition, a different combination of criteria should be selected for evaluating neighborhood walkability for utilitarian and recreational walking.

Table 2-5 showed all the purposes of walking behavior. The original data owns 15 categories of trip purpose from the questionnaire-based survey. Walking with the purpose code 1 - 4, 7, 9, 11 were classified as utilitarian walking behavior since all of these walking happened with a clear purpose and these purposes were related with their duties, such as go to work or go to school, in daily life. Walking with the purpose code 5 and 6 were classified as recreational walking behavior since these walking behaviors happened usual in people's leisure time and the purpose of the trips were for recreation. Walking with the purpose code 10 and 12 – 14 were classified as occupational walking which was not the target in this research. Walking with the purpose code 8 and 99 were also not included because of their unclear description. Table 2-6 gave the total number of sub trips and proportion of each category in order to understand the composition of each category. In order to reduce the uncertainty of this study, only the first two categories (utilitarian walking and recreational walking) were considered in the analysis.

After the extraction, the records were summarized based on PID to link the walking behavior with both the home location and the personal attributes of the respondents.

Table 2-5: Purpose code and corresponding categories in People Flow Data

Code	Value	Code	Value
1	To office	9	To send/pick up activity
2	To school	10	For selling and buying
3	To home	11	For appointment
4	To shopping place	12	To/for work (fixing and repairing)
5	For short recreation	13	To agri./forestry/fishery work
6	For sightseeing and leisure	14	Other business purpose
7	For medical treatment	99	Others
8	For other private purpose		

(Data source: CSIS, University of Tokyo)

Table 2-6: The number of sub trips and proportion of each category in People Flow Data

Purpose	**Total number of sub trips**	**Proportion (%)**
To office	2,701,891	22.18
To school	1,199,986	9.85
To home	5,213,859	42.79
To shopping place	885,258	7.27
For short recreation	633,864	5.20
For sightseeing and leisure	142,310	1.17
For medical treatment	218,333	1.79
For other private purpose	548,893	4.51
To send/pick up activity	120,764	0.99
For selling and buying	44,796	0.37
For appointment	243,824	2.00
To/for work (fixing and repairing)	32,914	0.27
To agri./forestry/fishery work	3,948	0.03
Other business purpose	166,731	1.37
Others	26,239	0.22

(Data source: CSIS, University of Tokyo)

2.6 Neighborhood definition

Associations between attributes of neighborhood environment and physical activity which includes walking behavior have been revealed by many studies. However, it is still not clear that what is the proper size of the neighborhood for measuring these neighborhood environment attributes. Neighborhood scale refers to the area at which the associations between the built environment and physical activity are investigated (Koohsari et al., 2013). Administrative boundaries defined by the government have been the most commonly applied scale (Riva et al., 2007). But in recent years, more work utilizing different sizes of buffer generated from residential addresses has been published (Colabianchi et al., 2007; Feng et al., 2010). When different neighborhood scales are applied, different associations with physical activity are shown. For instance, one study (Learnihan et al., 2011) demonstrated street connectivity, residential density, land use mix, and retail floor area, calculated at a 15-min street network walking distance from home, predicted walking for transport. But, these associations became non-significant when the measures were calculated at the suburb or census collection district scales. Research in Northern Ireland found that when applying a 1,000 m buffer, the correlation between physical activity and street connectivity was higher than the correlation under a 500 m buffer (Ellis et al., 2015).

The scale problem is defined as changes in results because of the number of units of analysis in a certain area and the zoning problem refers to differences in results when the same number of units is regrouped differently (Openshaw and Taylor, 1979). A number of studies detecting the scale problem by exploring the concept of activity spaces and neighborhood definitions in relation to walking have been published in recent years (Boruff et al., 2012; Chaix et al., 2012; Mitra and Buliung, 2012; Perchoux et al., 2013;

Villanueva et al., 2014).

The optimal scales for neighborhood environment attributes supporting physical activity differs by population, type of physical activity, and the attribute being investigated. For instance, it is probable elderly people and children will walk for shorter distances compared with functioning adults. In a relevant study (Hanibuchi et al., 2012), the authors set a radial distance of 500 m as representing the easily accessible space for older adults. On contrast, a research focusing on the walkability for adults defined the neighborhood as the area within a 10-15 min walk (approximate 1 km) from home. Other research also discussed that people will walk further to access a high speed, high-quality public transport network (e.g., train) than when accessing a lower speed public transport mode (e.g., bus) (Koohsari et al., 2013). Considering the previous studies as well the target group of people in this thesis, buffer area with a radius of 1 km from the residence's point was defined as the neighborhood for measuring walkability.

2.7 Buffer analysis for measuring walkability

The buffer analysis for measuring walkability was based on the location of each individual's residence (Fig. 2-3). From each point of residence's location, the 1 km buffer was created for summarizing the objective features inside each person's neighborhood. Figure 2-3 was an example with the objective data including the information of land use, bus stop's location and park's location. From each buffer, the evaluation value of these three criteria were calculated. Then the value was assigned to the residence's point. As a result, each point owned the new attributes of the evaluation results of all the criteria. With the PID available in both the attribute table of criteria related to neighborhood environment and the UWT and RWT of individuals, the relationship between actual walking time and simulated walkability could be detected. However, when trying to detect the spatial patterns of the results, the point data was not clear for observation and spatial patterns were hard to be detected with a lot of overlaid points. As a result, all the results were summarized by the standard 1 km × 1 km grid net established by the Geospatial Information Authority of Japan. The value of each grid was determined by the average value of all the residential points that fell into this grid. There were two objectives for this approach: creating standard data and visualization. Data summarized by the standard 1 km × 1 km grid net was applicable for comparative studies with other social and economic data published by the Japanese government which utilized the same unit. Instead of point-based results, the grid-based results were clearer for visualization and easier for detecting the spatial patterns of the results from the perspective of the urban structure.

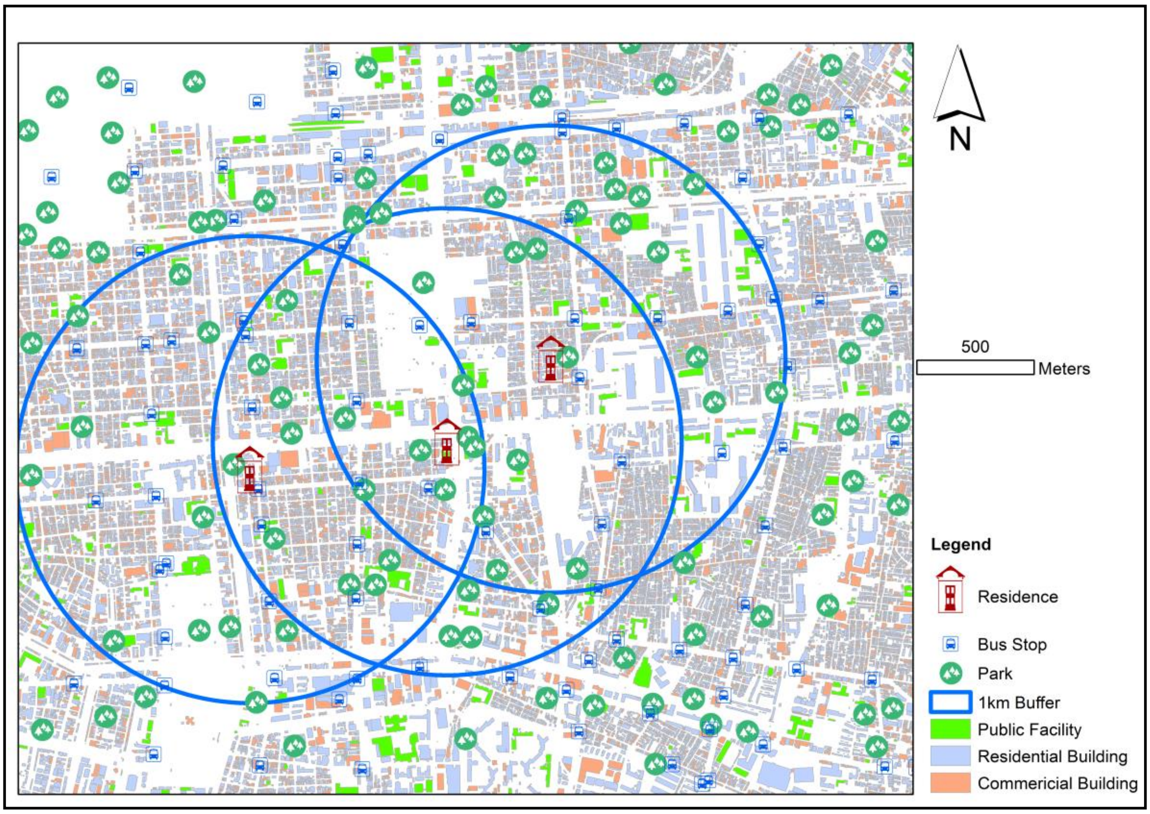

Figure 2-3: An example of buffer analysis for measuring walkability

2.8 Data collection and processing for measuring walkability

As mentioned in the literature review (chapter 1.3), different combinations of factors were utilized for measuring walkability considering the location, purpose, or research objects. In this study, eight factors were selected to evaluate the neighborhood environments including residential density, street connectivity, land use diversity, bus stop density, railway station accessibility, sightseeing spots accessibility, greenness density and parks density. The first three criteria are widely used in the evaluation of neighborhood environment and walkability in the previous studies (Jun and Hur, 2015; Lamíquiz and López-Domínguez, 2015; Sundquist et al., 2011). The other two factors, bus stop density and railway station accessibility, were included in this study since residents in TMA relied a lot on the public transportation in their daily lives. The last three factors were selected considering the attractiveness (sightseeing spots accessibility, greenness density) and comfortability (parks density) of the environment. The data source and process for these factors are described in the followings.

2.8.1 Residential density (RD)

Locations of residential buildings in TMA were derived from Zenrin© TOWN II digital maps. The first step was the combination of all the town maps. More than 200 layers were merged together with the function in the ArcGIS® software package, version 10.2. The next step was to extract residential buildings from all the buildings by the attribute of type. This step made the total number of features decreased from 16.4 million to 9.2 million. After this, a point-based resident's location layer obtained from the People Flow Data was added for creating the neighborhood buffers of each person. With overlay analysis, the count of residential buildings in each buffer was summarized and this value was made as the RD of each residence.

2.8.2 Street connectivity (SC)

In this study, SC was evaluated by the number of intersections within each neighborhood. Data from OpenStreetMap Project were utilized to get the road layer. Later, according to the description of the road categories, only the roads available for walking behavior were extracted. Next, the “network analysis” function, which is available in the ArcGIS® software package, version 10.2, was used to building road network and get intersections. Finally, the layer of neighborhood buffers created before were overlaid with the layer of intersections to get the count of intersections within each neighborhood as the value of street connectivity.

2.8.3 Land use diversity (LUD)

The original data used for the measurement of LUD came from the 100 m ×100 m land use mesh data included in the National Land Numerical Information constructed by the Japanese government. The original data had a number of 12 land use categories. Later they were reclassified into five categories since the purpose of evaluating this factor was to detect potential destinations for people’s walking behavior. The five categories included: single-family residential area, multifamily residential area, commercial area, public service area and green space. Land use diversity was calculated by the formula below and the value (d) represented the diversity of each person’s neighborhood:

$$d = -\frac{\sum k\,(p_k \ln p_k)}{\ln N}$$

where d is the diversity value; k is the category of land use; p is the proportion of each land use category; N is the number of land use categories. The equation resulted in between 0 to 1, with 0 representing a single type of all land use and 1, a developed area with all land use categories.

2.8.4 Bus stops density (BSD)

BSD was defined as the count of the bus stops in each neighborhood buffer. The original data recording the spatial location of bus stop were derived from the National Land Numerical Information. The number of the bus stops in each resident's neighborhood indicated the scale of accessible areas reached by taking a bus. With a higher bus stop density, residents in the neighborhood intended to have a higher possibility to choose bus as the movement means. When people choose to go out by bus, the utilitarian walking behavior usually happens since they need to take a walk to reach the bus stops.

2.8.5 Railway stations accessibility (RSA)

RSA was evaluated through the Euclidean Distance from each residential point to the closest railway station. The raster layer with a cell size of 100 m was created and the value of each cell was the distance to the nearest railway station. The neighborhood buffers were later utilized to get the average value of distance in each neighborhood. As mentioned above, good access to the public transportation facilities can encourage the utilitarian walking behavior with the purpose of reaching those facilities.

2.8.6 Sightseeing spots accessibility (SSA)

In this study, SSA was evaluated by calculating the kernel density of sightseeing spots within each neighborhood. The original data was from the National Land Numerical Information. The calculation of kernel density was done with the function in ArcGIS® software package, version 10.2. The sightseeing spots included landmarks such as temples, historical buildings, hot springs, and other natural or artificial spots defined by the local government. The higher kernel density of sightseeing spots within the neighborhood context implied residents there have a higher motivation to take a walk during their spare time.

2.8.7 Greenness density (GD)

GD was derived from the NDVI value which was derived from the Landsat imagery of Tokyo in 2008. Two Landsat 5 images were mosaicked to cover the study area and the value of NDVI was calculated by the formula below:

$$NDVI = \frac{NIR - VIS}{NIR + VIS}$$

NIR in Landsat 5 was band 4 while VIS in Landsat 5 was band 3. Through function of raster calculation in ArcGIS® software package, version 10.2, the NDVI value of the whole area was derived by a cell size of 30 m × 30 m. Later, the 1 km buffer of individuals was used to get the average value of NDVI each person's neighborhood area as the value of GD for them. The utilization of NDVI as the factor to evaluate the friendliness of neighborhood environment can be found in previous studies (Lwin and Murayama, 2011). The high value of NDVI would give people in this neighborhood a feeling of greenness in surrounding areas and this feeling could influence residents to have higher intention to take a recreational walk around.

2.8.8 Parks density (PD)

PD was measured by counting the number of parks in the neighborhood context. The original data was derived from the National Land Numerical Information. Like the two criteria mentioned above, the high density of PD was supposed to have a positive effect on the happening of recreational walking behavior since residents there had enough places to select for recreational walking.

2.9 Measurement of walkability

After the evaluation of the eight factors, the multiple regression analysis was processed to determine the suitable sets of criteria for evaluating utilitarian and recreational walkability. Equal weights were given to the value of each factor to calculate the final utilitarian walkability and recreational walkability respectively. The decision of weights was based on previous studies (Leslie et al. 2007; Sundquist et al. 2011). In the next step, all the values were normalized to force the values ranged from 0 and 1. After that, all the criteria were combined to calculate the indices of utilitarian walkability and recreational walkability for correlation detection with UWT and RWT of residents in TMA respectively.

2.10 Evaluation of the neighborhood context effect on walking behavior

The TWT, UWT and RWT derived from the People Flow Data contained all the walking behavior regardless of the location where the walking behavior happened. However, the evaluation of the neighborhood environment concentrated on evaluating the features in the neighborhood context which was a 1 km buffer from the residence. As a result, the correlation between the walking time and the neighborhood environment might be not very obvious and there is a need to extract only the walking happened inside the neighborhood context for checking potential relationship. When considering the form and structure of the People Flow Data, it was difficult to automatically extract the walking behavior based on the spatial location. According to the author's knowledge, the only possible way was to place the spatial location of each person to the map and count the points inside the neighborhood context. As a result, only 500 samples were randomly selected for the extraction as a case study to detect the neighborhood effect.

In general, when separating the walking behavior based on the neighborhood context, there are three types (Fig. 2-4). Type A represented the condition that all the walking happened inside the neighborhood context. The resident walked to a bus stop inside the neighborhood and take a bus directly to the company. After work, he/she took the same way back home. So all the walking time should be considered as the walking time inside the neighborhood context. Type B represented a mixed condition that walking happened both in the neighborhood and outside. The resident adopted the same method as the person in Type A to arrive in working place. But he/she walked back home without taking a bus after work. In this case, among the whole trip from working pace back home, only the walking inside the neighborhood was considered in this case study. Type C represented the condition that all the walking behavior happened outside the neighborhood. The resident drove a car to reach working place and back home. The only walking behavior of him/her might be a small trip to a shop nearby the working place. So that the TWT of this resident insider the neighborhood was 0.

After deriving the TWT, UWT and RWT inside the neighborhood context, the correlation detection with walkability was processed for find potential relationships.

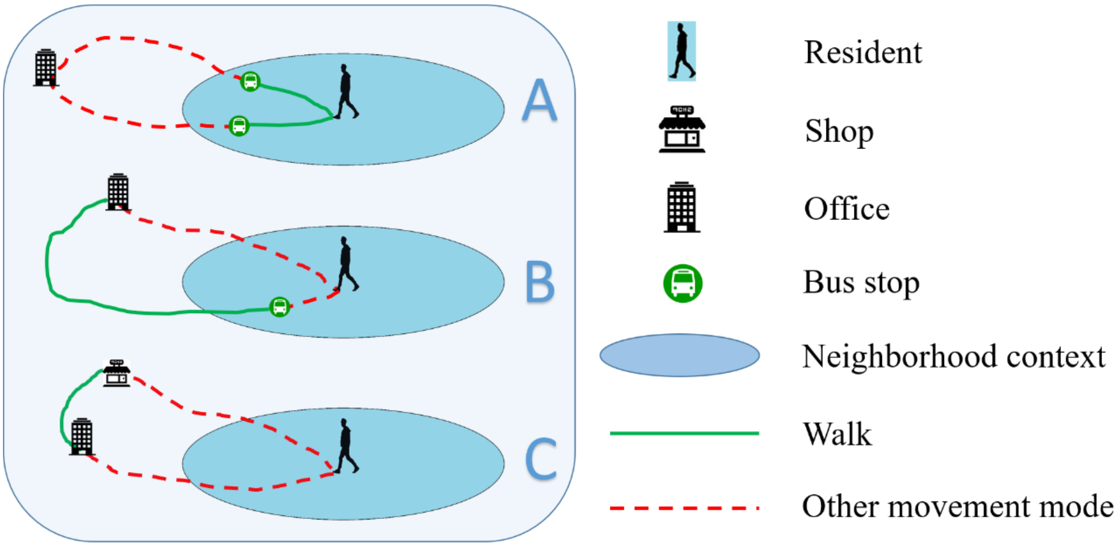

Figure 2-4: Different types of walking behavior considering the neighborhood context

Chapter 3

Walking behavior of residents in TMA

3.1 Spatial patterns and characteristics of walking behavior

Figure 3-1 revealed the average TWT of residents in TMA with an adoption of 1 km × 1 km grid net established by the Geospatial Information Authority of Japan. The value of each gird was derived from the average value of all the point data located in this grid. The No Data area were where the People Flow Data samples were not exist in 3:00 a.m. The dominant ranges of TWT in this area were 31 – 40 minutes and 41 – 50 minutes. Almost all of the grids belonging to the area of Tokyo city had a total TWT of more than 20 minutes. When focusing on the area where the residents had the longest TWT every day, it was hard to find the characteristics because these grids (average TWT > 1 hour) were scattered in the study area. On the other hand, the area with the lowest average TWT (less than 10 minutes) located mostly far away from the city center of Tokyo (the Tokyo Station), where could be regarded as the rural areas according to the definition in urban geography. Besides, another phenomenon was that area close to the railway in rural areas had a relatively higher average TWT (almost the same level as the Tokyo city) compared to other rural areas.

Figure 3-2 gave the rank of walking level which was determined by the average TWT. The rank was decided by which proportion the average TWT fell in considering the whole data set. For instance, the area with a rank of 1 represented that the average TWT of this area ranked at the last 10% of all the average TWT values in the study area. From the perspective of rank, it is clearer to find where the residence had the highest level of walking time. Like mentioned in the previous paragraph, level 10 area, which represented residents here had the longest walking time, scattered it the study area. However, we can clearly find that in the area close to the city center of Tokyo and the surrounding areas of Yokohama had the relatively higher walking level (rank 8 or 9). And the area with the lowest rank was located mostly in areas close to the municipal boundary of each prefecture where can be regarded as rural areas.

The two figures all showed that residents living in areas close to the city center tended to walk more than those who lived far away from the city center. In order to clearly detect this phenomenon, a multi-buffer analysis was used. City center was set as the location of the Tokyo Station. 10 buffers with an interval of 10 km were created and the TWT of residents belonged to each ring were summarized together to calculate the average TWT of each buffer ring. A trend can be observed from Table 3-1 that as the distance to the city center increasing, the average TWT decreased. In addition, three groups can be classified. In the area with a distance less than 50 km to the city center, the average TWT of the residents remained at around 39 minutes. A relatively obvious interval with the threshold of 50 km can be found and the second group included areas with a distance of 50 – 90 km to the city center. The average TWT of the residents in this area were around 35 minutes. The last group only included the area with a distance of 90 – 100 km to the city center. The average TWT of residents here decreased to only 30.7 minutes. The intervals between each group were around four minutes and the results supported the hypothesis that with the increase of the distance to the city center, residents intended to have less time spending on walking in daily life.

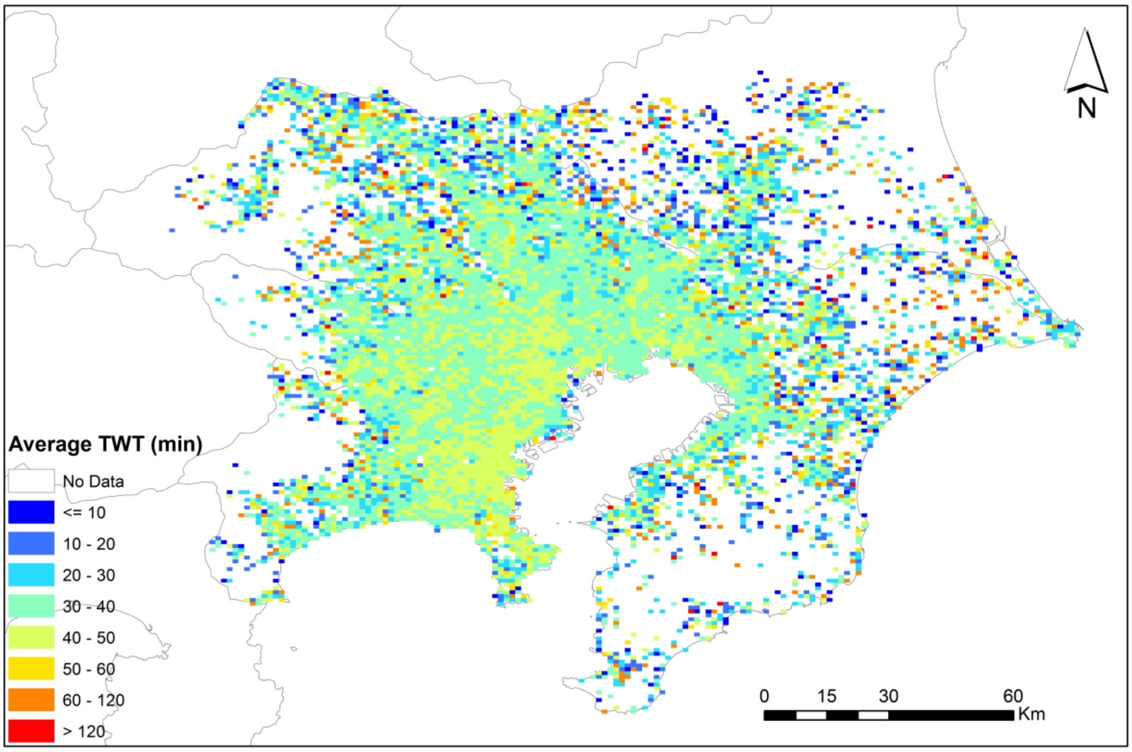

Figure 3-1: Average total walking time of residents in TMA

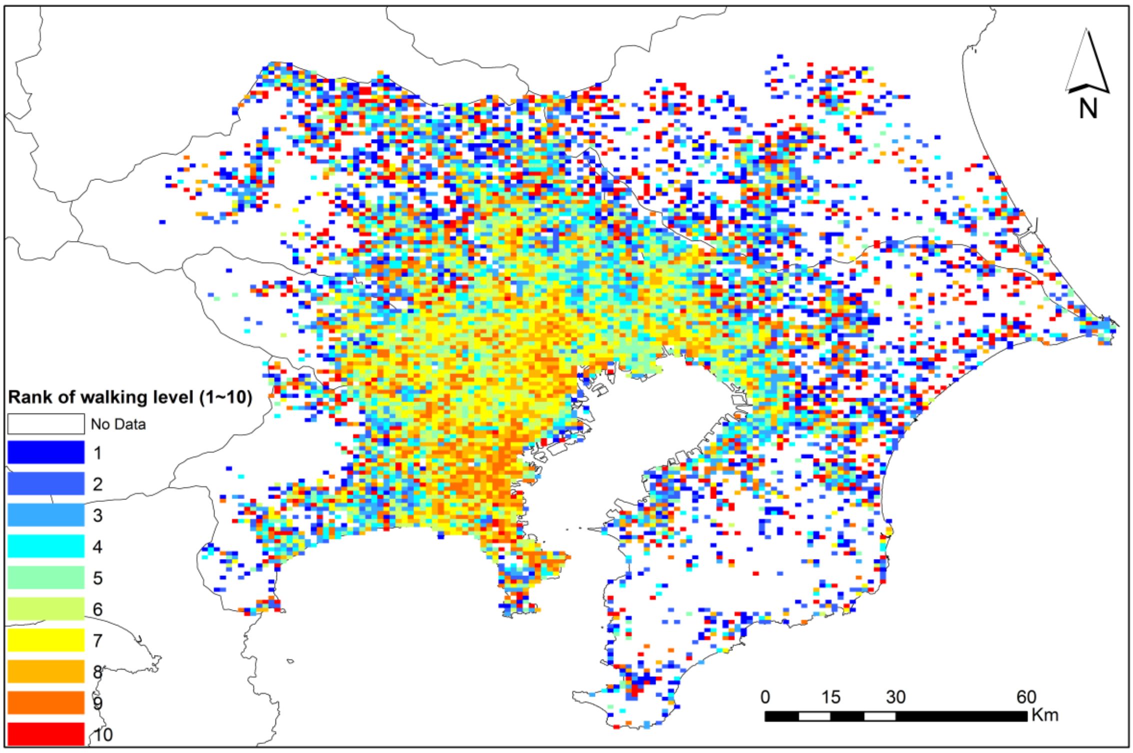

Figure 3-2: Rank of walking level of residents in TMA

Table 3-1: The relationship between the distance to the city center and the TWT

Distance to City Center (km)	**Number of People**	**Average TWT (min)**	**Maximum TWT (min)**
0 - 10	56,636	40.31	350
10 - 20	137,572	38.91	610
20 - 30	153,979	39.38	518
30 - 40	129,285	39.69	494
40 - 50	58,784	38.59	525
50 - 60	19,672	35.71	258
60 - 70	8,960	36.01	316
70 - 80	7,958	34.56	267
80 - 90	3,196	35.67	219
90 - 100	747	30.70	130

3.2 Utilitarian walking behavior

Following the same method mentioned in chapter 3.1, the results of average UWT of residents in TMA were shown by Figure 3-3 and Figure 3-4. From Figure 3-3 it was clear to find that the dominant range of average UWT in TMA was between 31 minutes and 40 minutes. Similar to the results of TWT, the Tokyo city, together with the Yokohama city and the areas close to the railway were occupied by this range. Also, areas with low average UWT concentrated at the rural areas. However, the spatial location of areas with a higher level of UWT differed with the results of TWT. Most areas with orange color (1h < UWT ≤ 2h) or red color (UWT > 2 h) were speared far from the city center. Some areas with high level of average UWT even appeared next to those areas with the lowest UWT value in rural areas. The reason below was considered related to this phenomenon:

Residents in these areas had a high possibility to work in places far away from their residence and this might cause two results: residents choose to drive directly to working place so that they had very low UWT or residents choose to walk/use the public transportation so that they earned a lot of UWT during the way to working place/railway stations and bus stops.

Figure 3-4 provided a different view of the result by ranking. Besides the rural areas where owned the highest UWT, some areas near Yokohama city and some areas close to the southern coastline also had the highest rank of residents' UWT level. This indicated a finding that residents living in or close to Yokohama might have more utilitarian walking compared with residents living in the Tokyo city. For other spatial patterns, Figure 3-4 remained consistency with the Figure 3-3 that residents in Tokyo city and surrounding areas had the moderate UWT and residents living in rural areas had a low level of utilitarian walking in daily life.

The next step is to see the characteristics of the ratio of UWT to TWT. UWT's proportion in the TWT of individuals was summarized with the standard 1 km × 1 km grid (Fig. 3-5). Firstly it is obvious that UWT had a high proportion (over 80%) of TWT in most of the study area. Although low proportion (less than 50%) existed, most of them belonged to areas lack of enough samples which might cause bias and uncertainty of the results. These revealed that for residents living in TMA, utilitarian walking was the main part of their walking behavior. The city area of Tokyo was mainly occupied by the proportion range between 80% and 90% and this could be regarded as the normal level of residents living in the Tokyo city. In addition, areas with the highest proportion (90% - 100%) concentrated on the eastern part of Tokyo city where was known as the main residential areas of Tokyo and some rural areas close to the municipal boundaries. Besides, areas alongside the railway lines towards northwest from the city center had both high proportion area (90% - 100%) and low proportion area (60% - 70%) while areas alongside the railway lines towards northwest were dominated by the highest level of proportion. This reflected the difference in the degree of reliance among residents living along the two railway lines.

Finally, the multi-buffer analysis was done for detecting the effect of distance to the city center on people's utilitarian walking behavior. We can still detect a trend from Table 3-2 that with the increase of the distance, the average UWT reduced. However, the intervals between UWT of each buffer ring were not very obvious except for the area with the longest distance to the city center (90 – 100 km). The average UWT of areas within 50 km to the city center could reach 34 minutes except for the 40 – 50 km ring (33.85 minutes). For the rings from 50 km to 90 km, the average UWT decreased to around 32 minutes with a 2minutes interval compared to inner areas (within 50 km). When the distance to city center reached the 90 – 100 km ring, the average UWT decreased immediately to 27.84 minutes with an interval of more than 4 minutes. Average TWT and UWT all proved that people living in areas close to the boundary of TMA might be a lack of walking on weekdays.

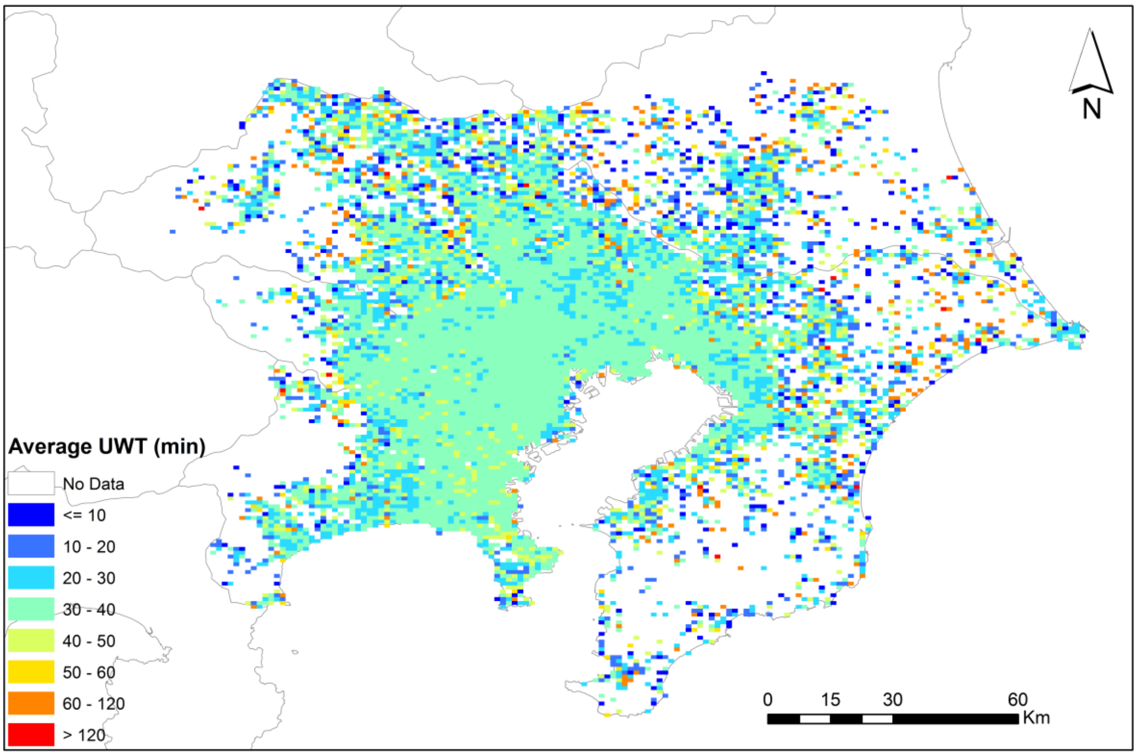

Figure 3-3: Average utilitarian walking time of residents in TMA

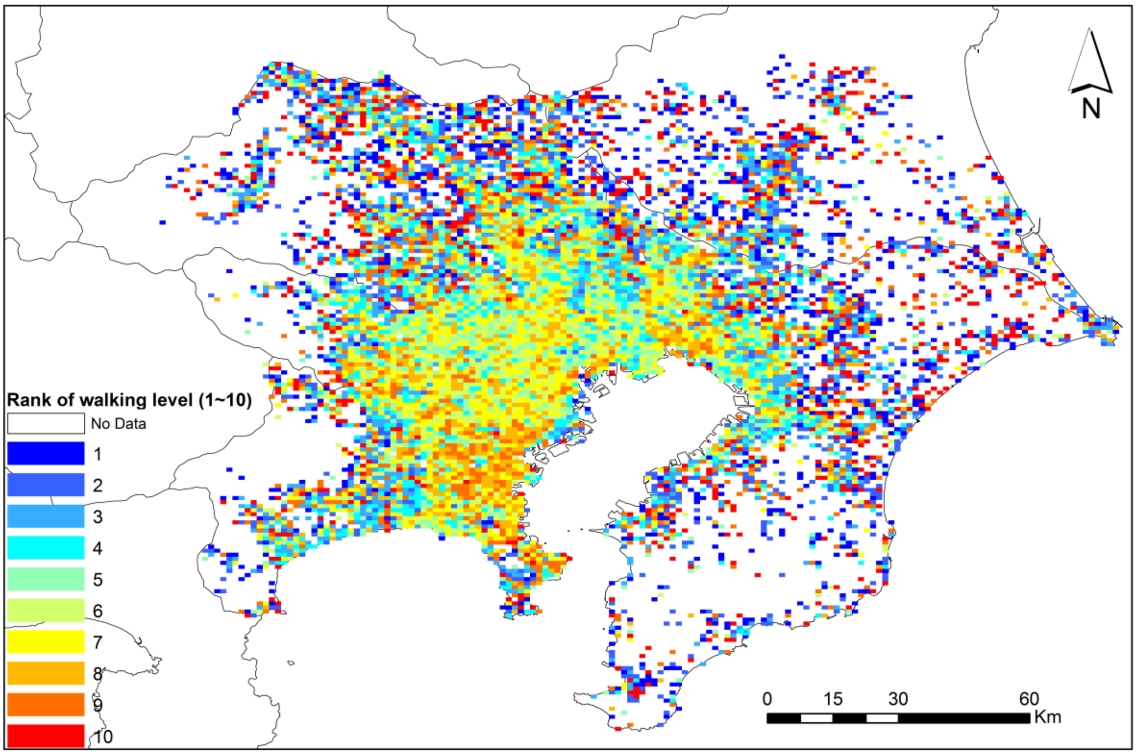

Figure 3-4: Rank of utilitarian walking level of residents in TMA

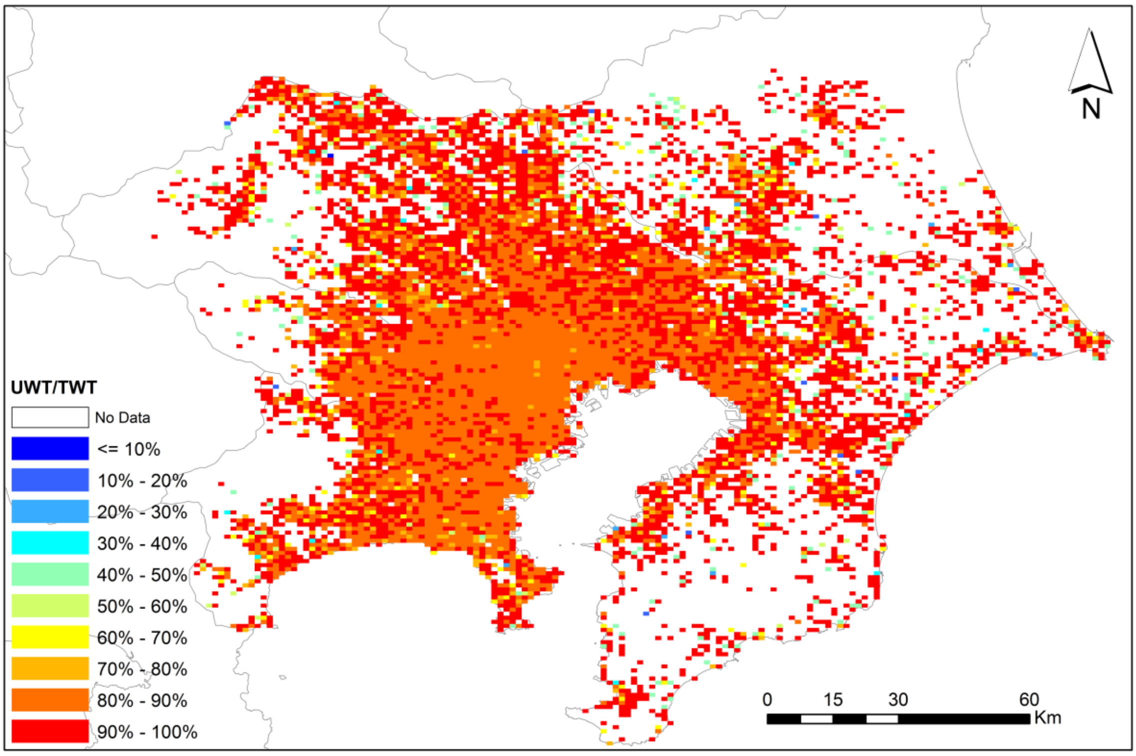

Figure 3-5: Ratio of utilitarian walking time to total walking time

Table 3-2: The relationship between the distance to the city center and the UWT

Distance to City Center (km)	Number of People	Average UWT (min)	Maximum UWT (min)
0 - 10	56,636	34.56	227
10 - 20	137,572	34.12	610
20 - 30	153,979	34.80	381
30 - 40	129,285	34.97	494
40 - 50	58,784	33.85	434
50 - 60	19,672	31.60	227
60 - 70	8,960	32.45	182
70 - 80	7,958	31.40	242
80 - 90	3,196	32.26	177
90 - 100	747	27.84	106

3.3 Recreational walking behavior

Figure 3-6 showed the average RWT of residents in TMA and Figure 3-7 ranked the results with the method mentioned above for comparing different areas. The dominant category of average RWT in TMA was from 11 minutes to 20 minutes, followed by the ranges of 21 – 30 minutes and less than 10 minutes. Since the Person Trip Survey was done on Friday, it could be concluded that residents in TMA normally had less than half an hour time for recreational walking during weekdays. The area had relatively higher average RWT (over 50 minutes) rarely appeared in rural areas and the distribution of these areas didn't have any spatial patterns. When focusing on the grids with the lowest average RWT, it could be found that alongside the railway lines to the northeast, north, and northwest, there were a lot of areas (girds) having an average RWT of fewer than 10 minutes.

This phenomenon was clearer in Figure 3-7 when all the grids were ranked by their average value of RWT. Along the three railway lines concentrated plenty of areas where residents' RWT ranked last compared to the whole study area. The reason for the low level of RWT was considered to be related to the characteristics of residents with a preference of living close to the public transportation facilities. Normally, people chose to live in areas with a good accessibility to railways because of they relied on the transportation system a lot in daily life. And in most cases, they used subways for the commuting activity between homes and working places in daily life. As a result, they spent more time on the way to work compared to people living close to their working places and they might not have too much spare time to enjoy recreational walking during the weekdays. Except for this finding, the ranking map of average RWT also showed that areas with a relatively short distance to the city center had a moderate rank while rural areas far away from the city center both had a possibility to have areas with a high level or low level of average RWT. However, by comparing Figure 3-7 to Figure 3-4, it is obvious that recreational walking had more uncertainty than utilitarian walking because even neighboring grids in Figure 3-7 might have a big difference while in Figure 3-4, grid’s value was stable considering the surrounding areas.

Figure 3-8 revealed the ratio of RWT to TWT from the spatial view and the similar phenomenon appeared along the railway lines as people living in these areas had the lowest ratio of RWT to TWT. This pattern supported the hypothesis about the characteristics of residents here mentioned in the previous paragraph. Besides, the value of the ratio in the Tokyo city was more stable compared to the patterns shown in Figure 3-6. In this context, although the actual recreational walking time might differ a lot between residents in Tokyo city, the proportion kept in the similar level so that the difference was from the total walking time per day, not the preference on recreational walking behavior.

Table 3-3 showed the relationship between average RWT and distance from residence to city center and this helped detect the effect of the city center on the presence of residents’ recreational walking. An increasing trend (from 17.76 min to 21.74) in the area with a distance of less than 50 km to the city center could be observed as long as the distance to city center increased. In this context, people living inside the Tokyo city intended to have more time on recreational walking if they live further to the city center. Outside the city boundary, residents had a relatively stable recreational walking time at around 20 minutes per day. The big difference between the ring of 80 – 90 km and the ring of 90 – 100 km might result from the lack of enough samples.

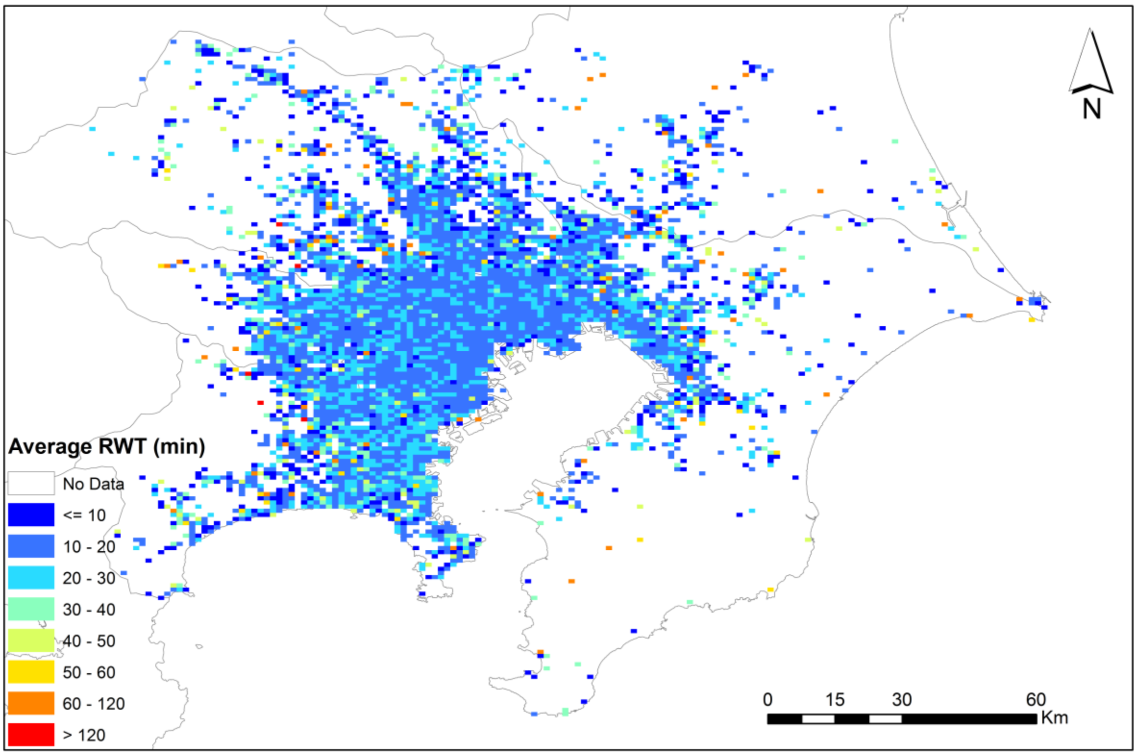

Figure 3-6: Average recreational walking time of residents in TMA

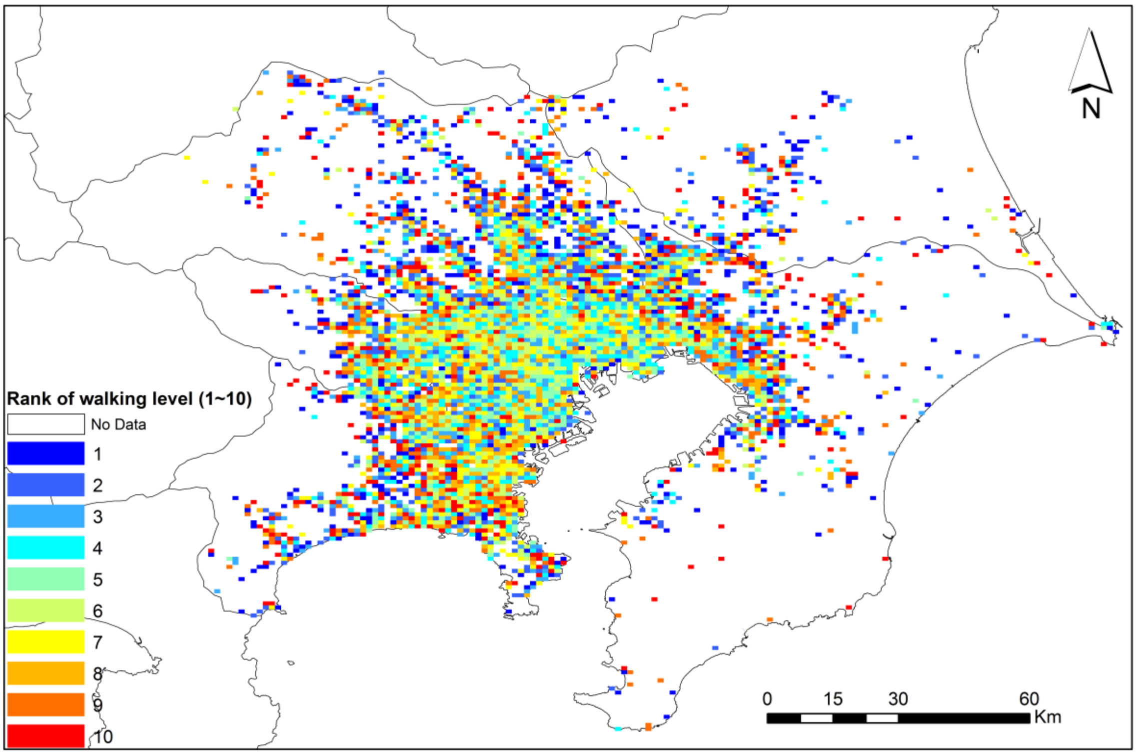

Figure 3-7: Rank of recreational walking level of residents in TMA

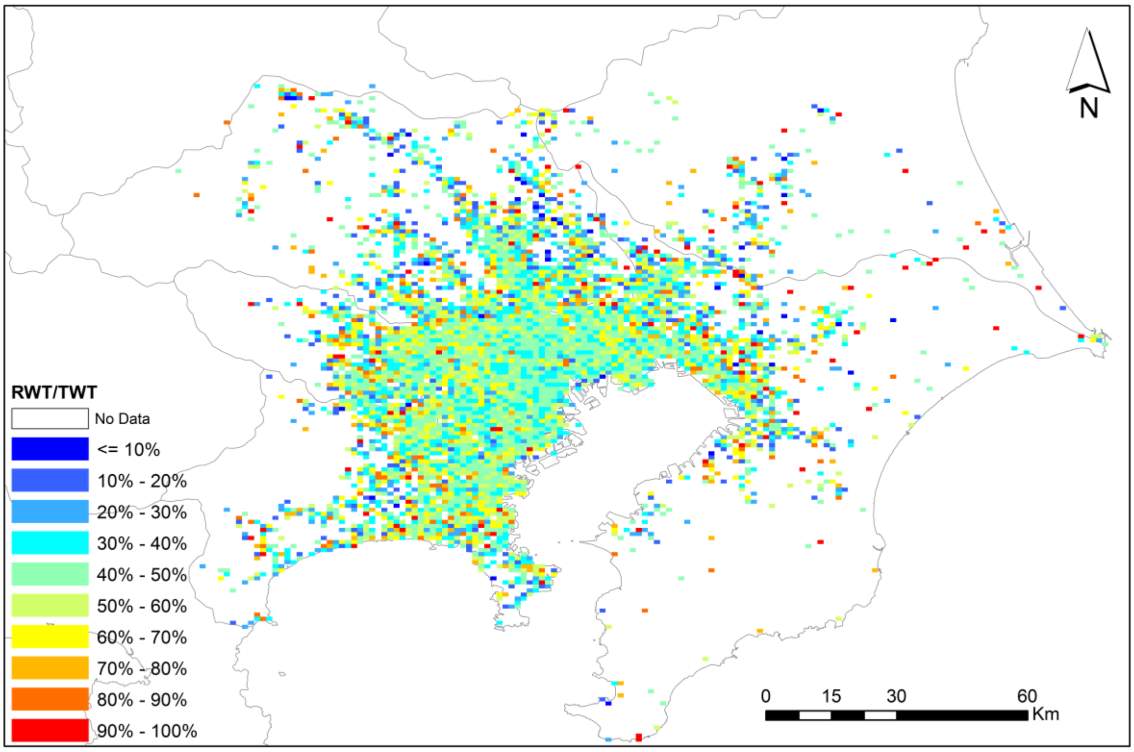

Figure 3-8: Ratio of recreational walking time to total walking time

Table 3-3: The relationship between the distance to the city center and the RWT

Distance to City Center (km)	Number of People	Average RWT (min)	Maximum RWT (min)
0 - 10	56,636	17.76	189
10 - 20	137,572	18.63	403
20 - 30	153,979	19.42	368
30 - 40	129,285	20.62	415
40 - 50	58,784	21.74	331
50 - 60	19,672	19.62	153
60 - 70	8,960	20.24	316
70 - 80	7,958	20.25	124
80 - 90	3,196	22.29	110
90 - 100	747	18.92	65

3.4 Characteristics of different types of walking behavior

The spatial patterns of residents' average total walking time, utilitarian walking time and recreational walking time were revealed in this chapter. In general, the spatial patterns of these three categories all showed consistency with the urban structure of TMA. Residents living in the 23 special wards of Tokyo as well as the Yokohama city had higher TWT, UWT and RWT. The railway lines showed a potential contribution to the amount of UWT but no contribution to the amount of RWT. People living in rural areas had the lowest walking time regardless of the walking types. This result revealed that people in rural areas of TMA relied much more on vehicles than people in urban and suburban areas of TMA. When checking the proportions, the results showed no significant differences among residents in urban, suburban and rural areas. The only pattern can be detected from the figures were that people living in areas close to the railway lines tended to have higher proportion of utilitarian walking in their whole walking behavior than people living far from the railway lines. The reason for this pattern was considered to be that people who prefer to live close to the railway lines had higher potential of choosing public transportation as their daily movement means and the movement from and to the stations increased the proportion of utilitarian walking time.

The multi-ring analysis showed similar results that with the increase of distance to the city center, the average TWT and UWT of the residents decreased while the RWT didn't change too much. Besides, significant intervals were found between areas with a distance of less than 50 km from the city center and areas with a distance of 50 to 90 km from the city center in TWT (4 min) and UWT (2 min). This indicated the boundary between suburban and rural areas were close to the buffer of 50 km to the city center.

Chapter 4

Effects of personal attributes on walking behavior

4.1 Effect of gender on walking behavior

The effect of gender difference on walking behavior is widely proved in previous studies (Trost et al., 2002; Cooper et al., 2005; Gebel et al., 2012; Kelley et al., 2016). In this study, the average TWT, UWT, and RWT were summarized from the People Flow Data to reveal the gender difference (Fig. 4-1). In general, males living in TMA had an average UWT of 36.05 minutes and RWT of 19.99 minutes while female's average UWT and RWT were 32.82 minutes and 18.84 minutes respectively. In this context, compared with females, males had 9.84% more UWT and 6.10% more RWT. In general, men tended to walk more than women from perspectives of both utilitarian walking and recreational walking. Several possible reasons were considered to be able to cause this result. For the case of utilitarian walking, it is mainly related to the commuting activity from residence to workplace. Considering there was a considerable proportion of women choose to become housewives after marriage, their utilitarian walking behavior might be affected because they didn't need to go to work in daily life. Although the daily pick up activity for children might increase the UWT for housewives, the increase was not obvious compared with the decrease of time in commuting to work place. The difference of RWT mainly resulted from the difference in the amount of spare time and the activeness to walking. In this context, compared with women, men living in TMA had a higher preference to walk in their spare time.

Besides the differences in average value mentioned above, the spatial patterns of gender difference in TMA were also detected (Fig. 4-2, 4-3, 4-4, 4-5). Only the spatial pattern of gender's effect was mapped because unlike the other two factors (age and occupation), gender was not related to the residential address. As a result, the gender effect on walking behavior could be observed from the perspective of urban structure. Figure 4-2 and Figure 4-3 showed that the dominant level of UWT in TMA for male and average both ranged from 31 minutes to 40 minutes per day. And the dominant level areas were located mainly in the Tokyo city and its surrounding areas. However, when checking the second level, the difference appeared that range 41–50 minutes covered second largest area for male while range 21–30 minutes covered second largest area for female. This might cause the 3.2 minutes difference of average UWT between male and female. Besides, they showed the similar spatial patterns that residents in the central area of TMA had a stable level of UWT and with the increase of distance to city center, the level of UWT showed a declining trend. However, the level of UWT in rural areas was not stable so that some areas with high average UWT (more than 1 hour) appeared mostly in rural areas.

When focusing on recreational walking behavior, the difference in spatial patterns was not obvious (Figure 4-4 and Figure 4-5). Range from 11 minutes to 20 minutes of average RWT dominated in both male and female. In addition, residents in some areas with a short distance to the city center had a higher level (21 min to 30 min). What's more, the lowest level appeared in rural areas with a trend to be close to the railway lines. Both for male and female, it is very rare to have a high level of RWT during weekdays. Areas, where residents here had a high RWT level (more than 1 hour) appeared occasionally in rural areas with neighboring areas in a much lower level. Considering the limited amount of samples in rural areas, the high level might be not very trustful.

In conclusion, the male did more utilitarian walking and recreational walking than women during weekdays in TMA. The spatial distribution of levels of UWT and RWT for male and female didn’t show a big difference.

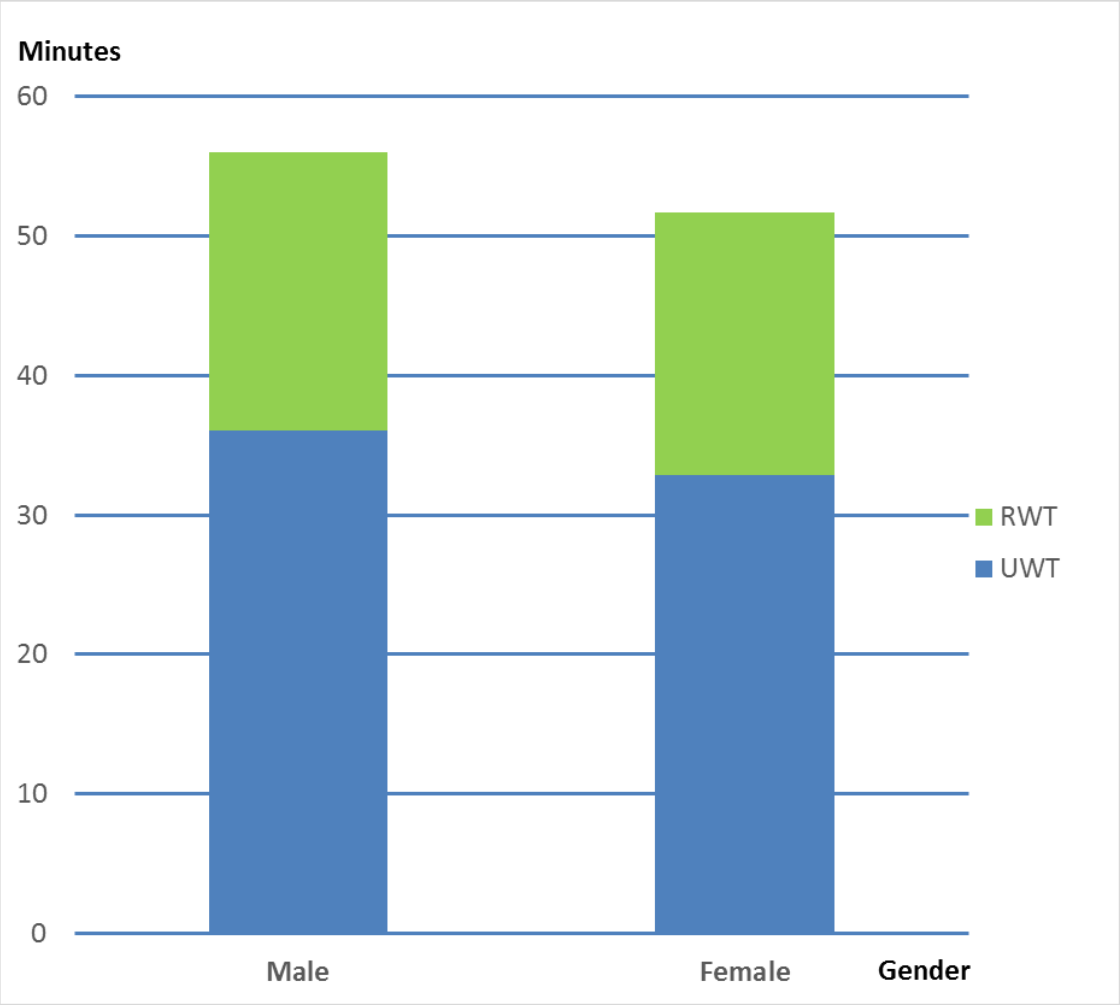

Figure 4-1: Gender difference in UWT and RWT

(Data source: CSIS, University of Tokyo)

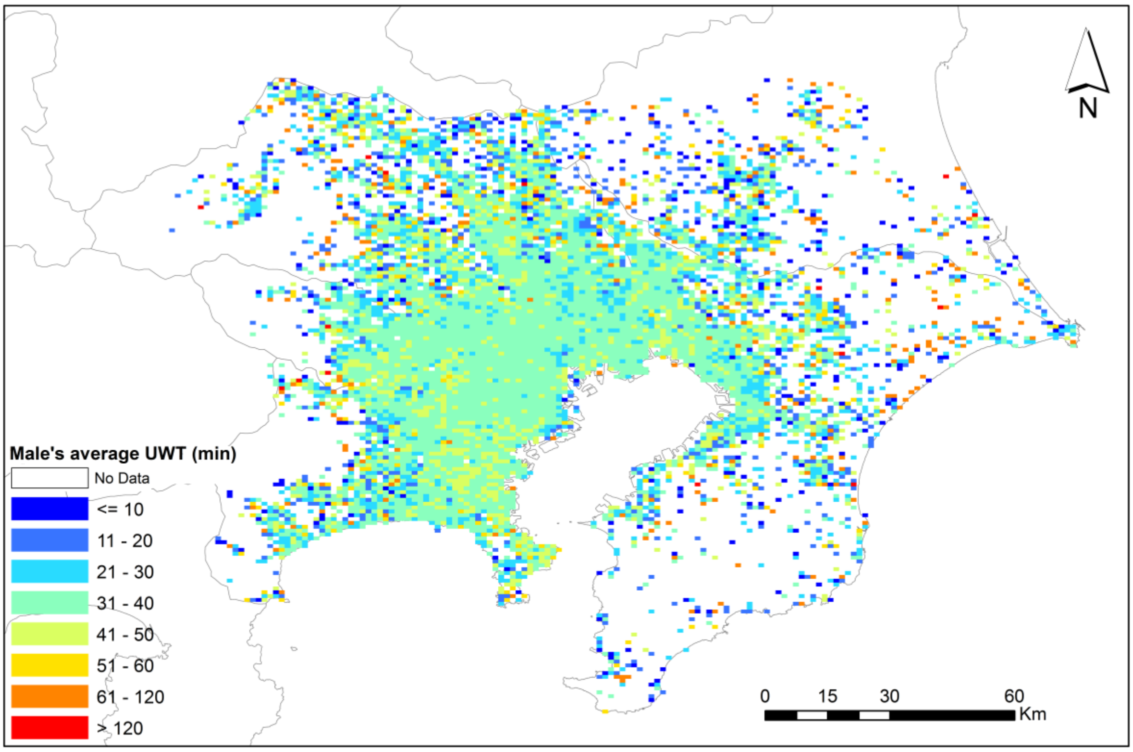

Figure 4-2: Male’s average UWT in TMA

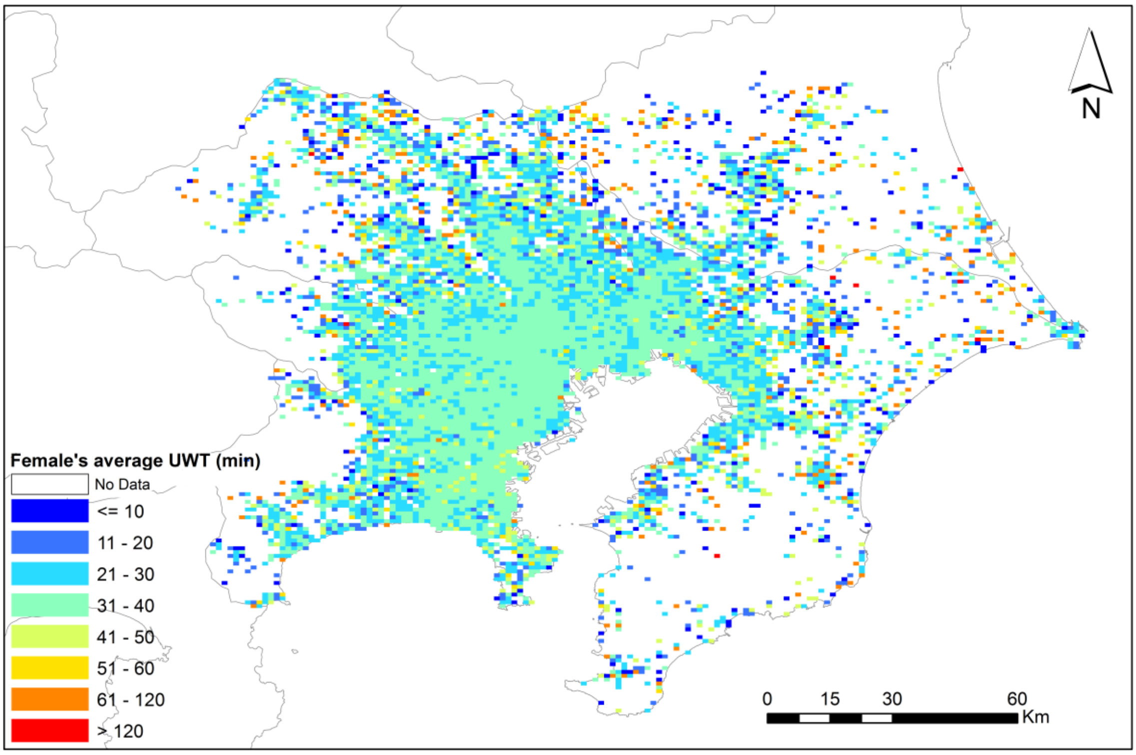

Figure 4-3: Female’s average UWT in TMA

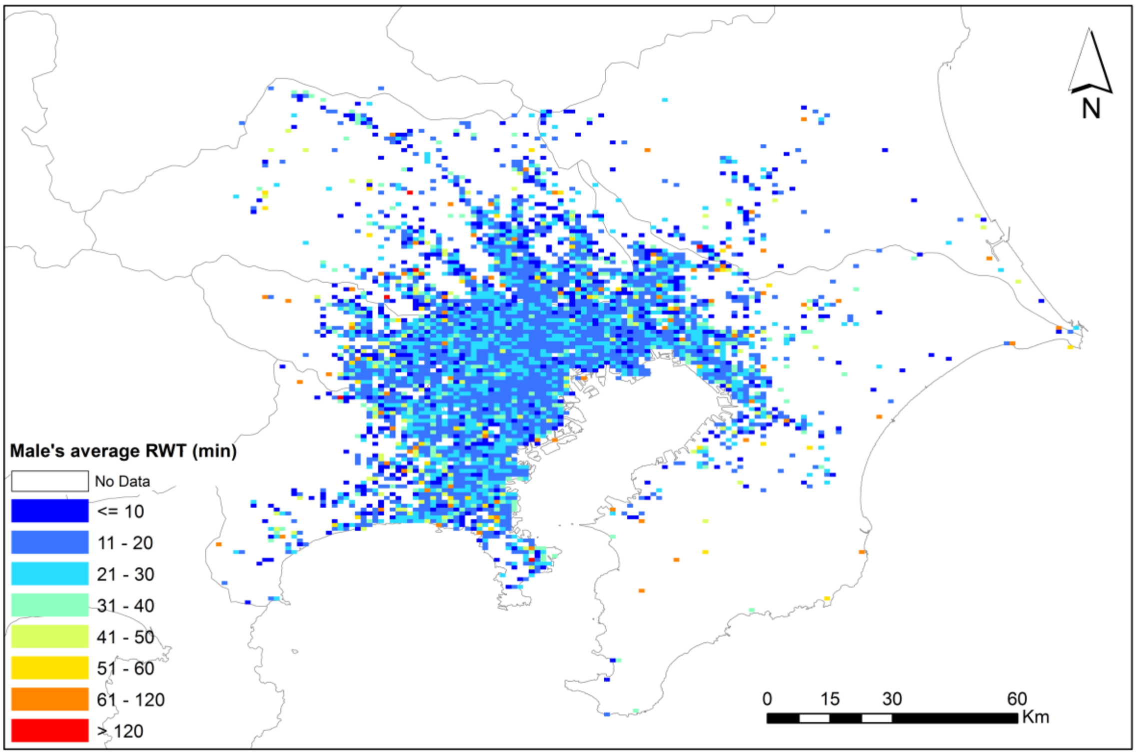

Figure 4-4: Male's average RWT in TMA

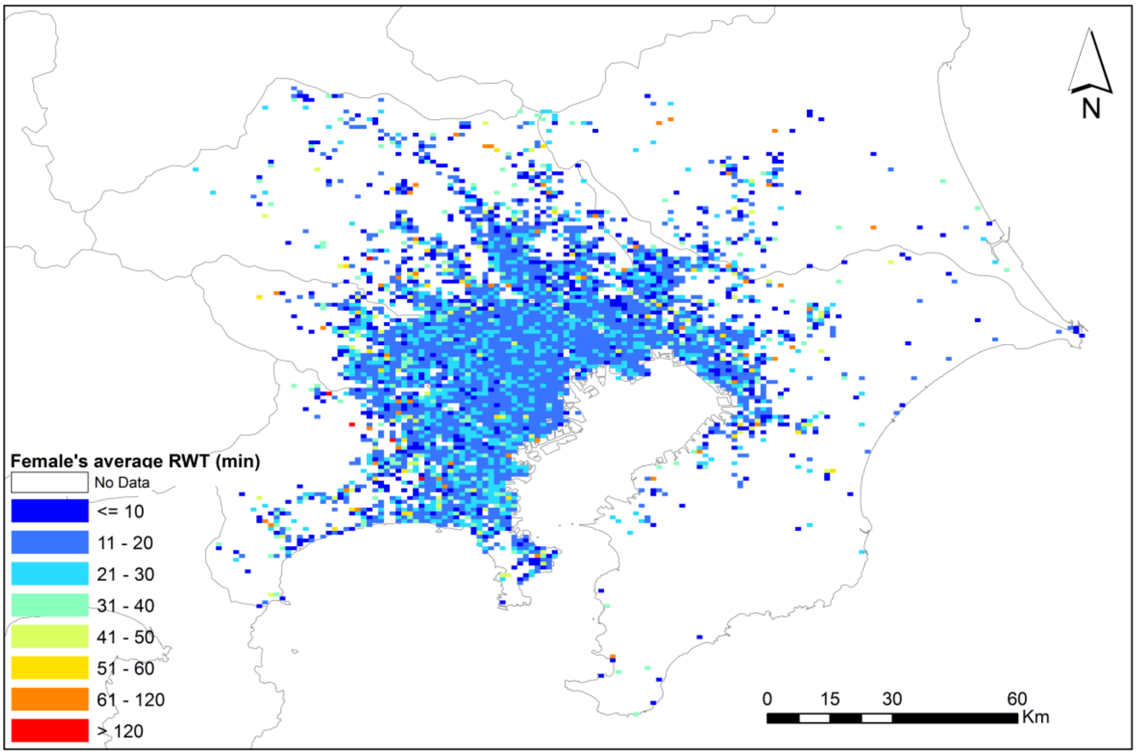

Figure 4-5: Female's average RWT in TMA

4.2 Effect of age on walking behavior

Age is another main factor been widely studied to detect its effects on walking behavior (Thielman et al., 2015; Ryan et al. 2016; Lee, 2016). Figure 4-6 showed the levels of UWT and RWT in different age groups. Table 4-1 gave the detailed values and proportion of UWT and RWT in each age group. The trends and patterns could be better concluded by separating three age groups: adolescents (age group 5-10, 10-15, and 15-20), labor force (age from 20 to 65) and retiree (age over 65).

For adolescence, the trend was simple that with the increase of the age, they spent more time on both utilitarian walking and recreational walking per day. When comparing with all the groups, adolescents had the highest level of UWT per day. In special, age group 15-20 had the longest average UWT (36.23 minutes) among all the groups. Most of the utilitarian walking behavior for adolescents in this age group was considered to go to school (or go to work). Considering most of them didn't have a car at this age, it is reasonable for them to have the highest UWT level. On contrast, adolescence's RWT was at a relatively low level compared to all. This might reflect they couldn't have too much spare time during weekdays and they were not interested in taking a walking for relaxing during this age.

For labor force which covered half of the age groups, the trends for UWT and RWT were revised from the graph. With the increase in age until around 40, people in this group did more utilitarian walking and less recreational walking during weekdays. The increasing trend of UWT changed into decreasing trend at the age group of 45-50 while the decreasing trend of RWT rotated at the age group of 35-40. The reason for the change in UWT was considered to be related with whether choosing vehicles as the mobile means or not. Since people at age of around 50 might be in an important position in companies, they might prefer to use vehicles instead of public transportation systems. The change in RWT was considered to be related with the preference of jogging among people in different age groups. In general, the labor force had a moderate level of UWT together with a low level of RWT.

For the retirees, they had the lowest level of UWT since most of them didn’t need to go to work every day. In this context, they owed the longest spare time compared to adolescence and labor force. As a result, they had the highest level of RWT. In fact, the average RWT of people in age groups over 60 years old all reached 20 minutes per day while no groups with age under 60 reached this level. The highest level belonged to age group 65-70, with an average RWT of 25.90 minutes per day, more than two times of the lowest level (age group 5-10, 12.18 min/day). And both the average UWT and RWT slimly decreased with the increase in age.

In conclusion, adolescences had the highest level of UWT and the lowest level of RWT. Labor forces’ UWT level was moderate and their RWT level was also at a relatively low level except for the people in age group 60-65. Retirees had the highest level of RWT while their average UWT were in the lowest level.

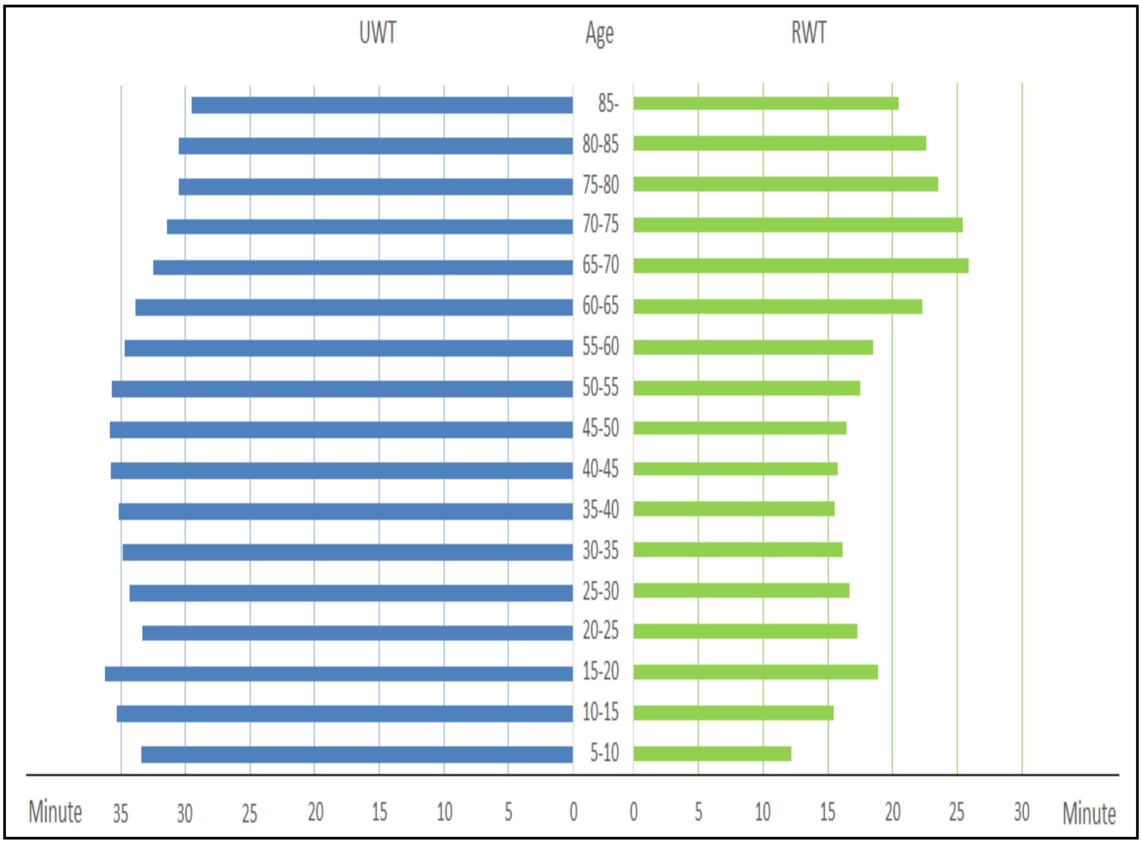

Figure 4-6: Age difference in UWT and RWT

(Data source: CSIS, University of Tokyo)

Table 4-1: UWT and RWT of people in different age groups

Age Group	UWT (min)	UWT Proportion (%)	RWT (min)	RWT Proportion (%)
5-10	33.42	73.29	12.18	26.71
10-15	35.35	69.57	15.46	30.43
15-20	36.23	65.71	18.91	34.29
20-25	33.32	65.89	17.25	34.11
25-30	34.34	67.35	16.65	32.65
30-35	34.84	68.38	16.11	31.62
35-40	35.14	69.31	15.56	30.69
40-45	35.75	69.42	15.75	30.58
45-50	35.90	68.63	16.41	31.37
50-55	35.71	67.10	17.51	32.90
55-60	34.74	65.21	18.53	34.79
60-65	33.89	60.35	22.27	39.65
65-70	32.52	55.67	25.90	44.33
70-75	31.41	55.25	25.44	44.75
75-80	30.56	56.48	23.55	43.52
80-85	30.51	57.40	22.64	42.60
85-	29.57	59.12	20.45	40.88

(Data source from: CSIS, University of Tokyo)

4.3 Effect of occupation on walking behavior

Occupation is another attribute included in People Flow Data and previous studies also proved this attribute had an effect on walking behavior (Barrington et al., 2015; Rachele et al., 2016). Figure 4-7 showed the average UWT and RWT of different occupations. Table 4-2 gave the detailed values and proportion of UWT and RWT in each occupation group. Before the description, it is needed to state that category number 10 (other occupation), 16 (not categorized) and 99 (unknown) were not included in the discussion because the description of these three categories was not clear.

First of all, people of occupation in all the groups had higher average UWT than RWT, even for those who were unemployed (code 15). Besides, the top three occupation order by average UWT were the manager (38.16 min), high school student (37.47 min) and professional (37.18 min) and the last three categories were house-wife (28.40 min), agricultural/forestry/fishery worker (30.12 min) and no occupation (30.87 min). On the other hand, the top three by RWT were no occupation (25.97 min), agricultural/forestry/fishery (21.73 min) and security service employee (20.84 min) and the last three categories were elementary and junior-high student (13.44 min), manager (15.12 min) and office worker (15.51 min). If we compare the differences between UWT and RWT among all the categories, the manager had the biggest difference (23.04 min) while no-occupation people had the smallest difference (4.9 min).

In order to further discuss the effect of occupation difference on walking behavior, all the occupations were classified into blue collar (code 1-3), white collar (code 7-9), service employee (code 4-6), students (code 11-13) and free worker (code 14 and 15). After the classification, it could be detected from Figure 4-7 that white collar had the longest average UWT per day. This implied that white-collar might spend more time on the way going to work in daily life. On the other hand, the free worker had the shortest average UWT since they didn’t have a stable destination to go in daily routine. The difference between different groups in terms of RWT was not as obvious as UWT. But the result kept consistency with the result of UWT that free worker had the longest average RWT because they had enough spare time while white collar had the shortest RWT as they didn’t have too much spare time during weekdays. The other three groups were in the moderate positions in terms of both average UWT and RWT.

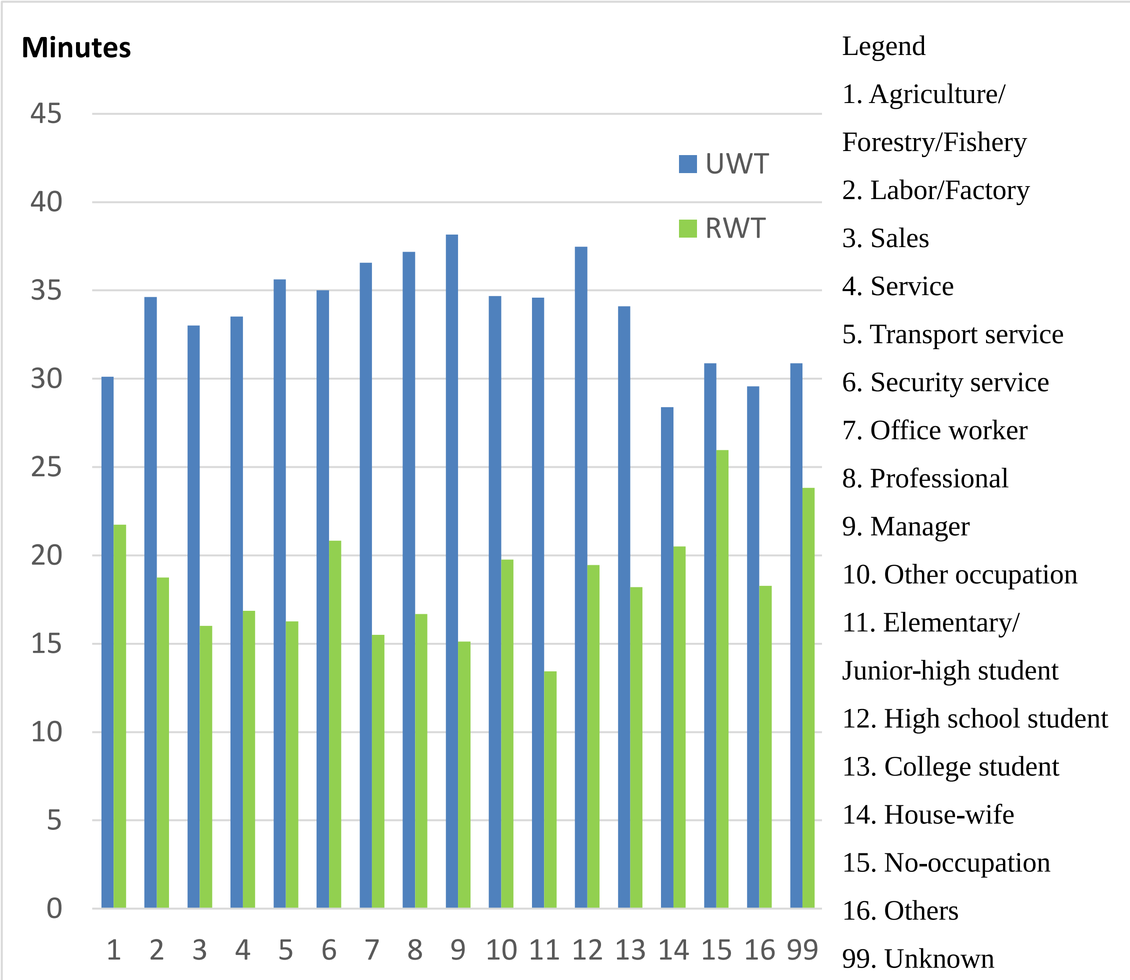

Figure 4-7: Occupation difference in UWT and RWT

(Data source: CSIS, University of Tokyo)

Table 4-2: UWT and RWT of people in different occupation groups

Occupation Group	UWT (min)	UWT Proportion (%)	RWT (min)	RWT Proportion (%)
Agriculture/ Forestry/Fishery	30.12	58.09	21.73	41.91
Labor/Factory	34.62	64.88	18.74	35.12
Sales	33.01	67.34	16.01	32.66
Service	33.53	66.54	16.86	33.46
Transport service	35.63	68.65	16.27	31.35
Security service	35.00	62.68	20.84	37.32
Office worker	36.57	70.22	15.51	29.78
Professional	37.18	69.03	16.68	30.97
Manager	38.16	71.62	15.12	28.38
Other occupation	34.68	63.70	19.76	36.30
Elementary/Junior-high student	34.59	72.02	13.44	27.98
High school student	37.47	65.82	19.46	34.18
College student	34.11	65.21	18.2	34.79
House-wife	28.40	58.08	20.5	41.92
No-occupation	30.87	54.31	25.97	45.69
Others	29.57	61.80	18.28	38.20
Unknown	30.87	56.44	23.83	43.56

(Data source from: CSIS, University of Tokyo)

4.4 Differences in utilitarian and recreational walking behavior from the aspect of personal attributes

This chapter revealed the effects of personal attributes on walking behavior. In general, men had more walking time than women regardless of the walking purpose. However, the difference didn't have any spatial patterns when allocating the walking time into the map. Age difference was more obvious when separating all the people into groups of adolescence, labor force and retirees. The results that labor force had higher UWT and retirees had higher RWT were reasonable since labor force spent more time on the way going to and going back from working places which were included in utilitarian walking while retirees had the most sparing time for their recreational activity which included recreational walking. The difference in occupation could also result the difference in walking behavior. Similar to the finding in comparing different age groups, white-collar workers and high school students had the highest UWT as they took a lot of utilitarian walking during their way to and back from working places or schools. On the other hand, No-occupation people and housewives had the highest RWT as they had the longest sparing time during weekdays.

These findings mentioned above proved the value of separating people into different groups when trying to detect the characteristics of walking behavior. Different personal attributes affected people's walking behavior in different aspects and degrees. Other attributes such as salary, driving status, marital status and education might also be valuable to be analyzed if there were available data.

Chapter 5

Evaluation of neighborhood environment by measuring walkability

5.1 Criteria for evaluating neighborhood environment

As mentioned in chapter 2, eight criteria were selected for evaluating the neighborhood environment. Since this study separated the walking behavior into utilitarian walking and recreational walking based on the purpose, it is necessary to evaluate the ideal neighborhood environment for utilitarian walking and recreational walking respectively. In this study, the terms of utilitarian walkability and recreational walkability were created for detecting the friendliness of the neighborhood environment to utilitarian and recreational walking. The evaluation results of the eight selected criteria were shown in this chapter by the standard 1 km^2 in order to detect the spatial patterns. The value of these eight criteria were assigned to each person for the further analysis to determine suitable combinations in calculating utilitarian and recreational walkability.

5.1.1 Residential density

Results of RD (Fig. 5-1) showed that except for the Chu’o ward which was located in the central of TMA, the residents in the other 22 special wards of Tokyo all had a high RD. Also, the residents living in or close to the Yokohama city had a high RD. This was a common pattern since urban areas had much higher population density than rural areas. Besides these areas, the high RD area appeared along the railway lines which revealed that people intended to live in places with a good accessibility to the railway stations. The spatial patterns of RD can be understood from the perspective of urban structure: The suburban areas close to the city center were usually designed as the residential areas with a high density of residential buildings. The low value appeared in both the central area of Tokyo and the rural areas of the metropolitan area. Low RD in the central area resulted from that most of the buildings there was commercial land use. On the other hand, rural areas had low RD because of the low population density and the dominant residential building type (single-family house) there.

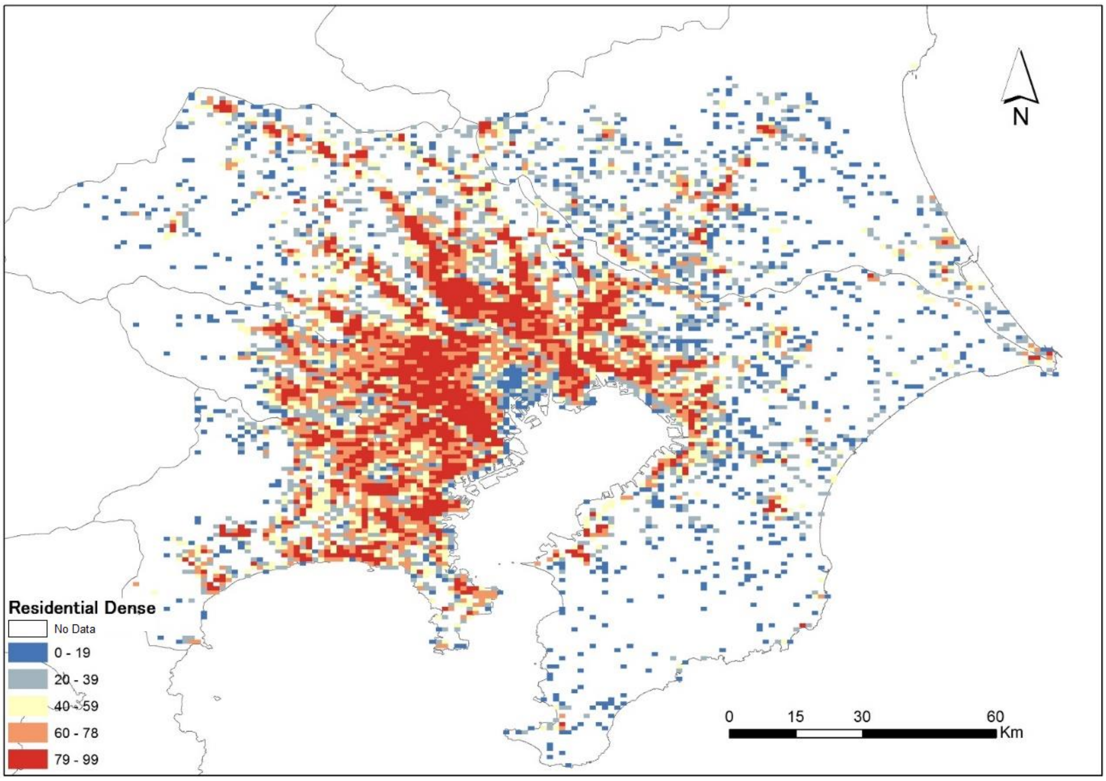

Figure 5-1: Residential density of TMA

5.1.2 Street connectivity

SC showed a similar spatial pattern with the residential density (Fig. 5-2) that the highest value appeared in the urban areas with a short distance to the urban core while the lowest values appeared in the rural areas far from the urban core. The northwest part of the Tokyo city (near Shinjuku Area), together with the Yokohama city, had the high density of intersections which implied tremendous people flow there. Residential areas in Tokyo city, which were concentrated close to the city boundary, had a moderate level of SC because usually the people flow in residential areas was fewer compared to people flow in residential areas so that the demand for SC was not as strong as commercial areas. Rural areas had the lowest level of SC since the population density was low and the number of facilities there was also at a low level. As a result, it was not necessary to build a big amount of roads there.

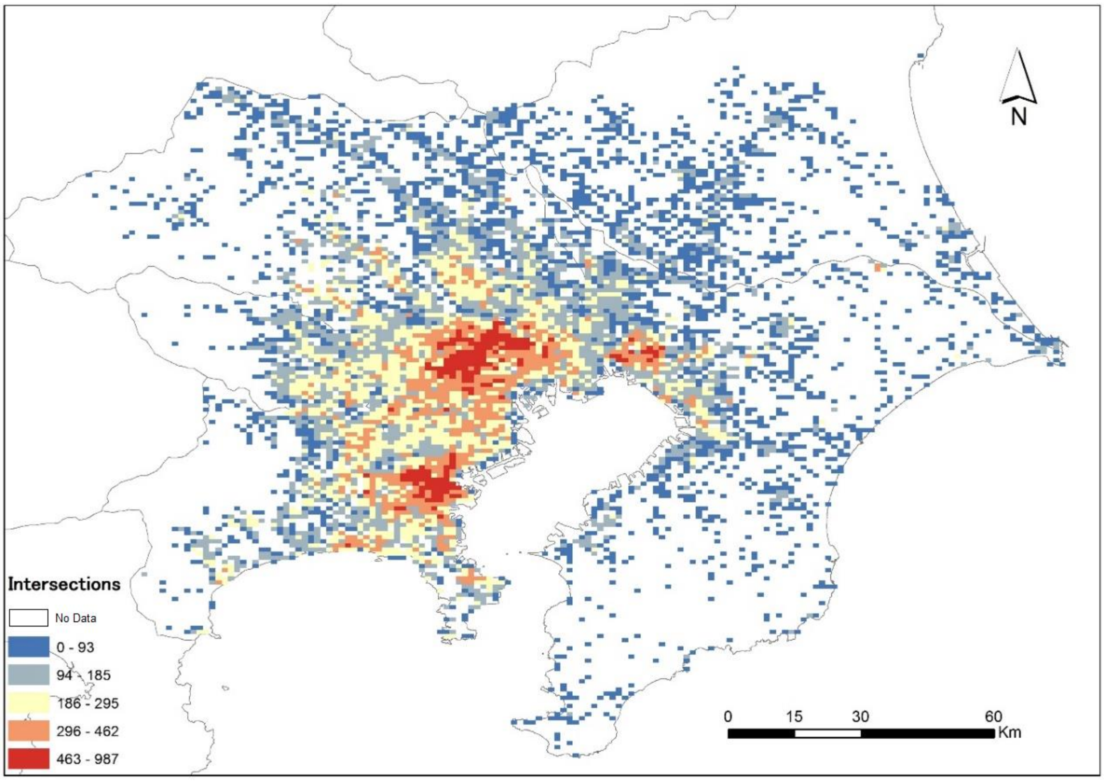

Figure 5-2: Street connectivity of TMA

5.1.3 Land use diversity

The result of LUD (Fig. 5-3) had a slim difference compared with the first two criteria. Although the lowest value was still assigned to the rural areas, the highest value appeared both in the urban core of Tokyo city and Yokohama city, and the urban areas with a short distance to the urban core. The diverse land use in the urban core resulted from the need to serve the big flowing population passed there every day. Besides, city center often served as a commercial center for residents' shopping and other recreational behavior. As a result, plenty of land use categories were needed there. The high LUD in some residential areas showed that some areas had prepared enough facilities to serve convenient daily life for residents there. On contrast, some suburban areas had the same low values as rural areas. This indicated that some of the residential areas in Tokyo might be a lack of enough facilities for daily life in the neighborhood context.

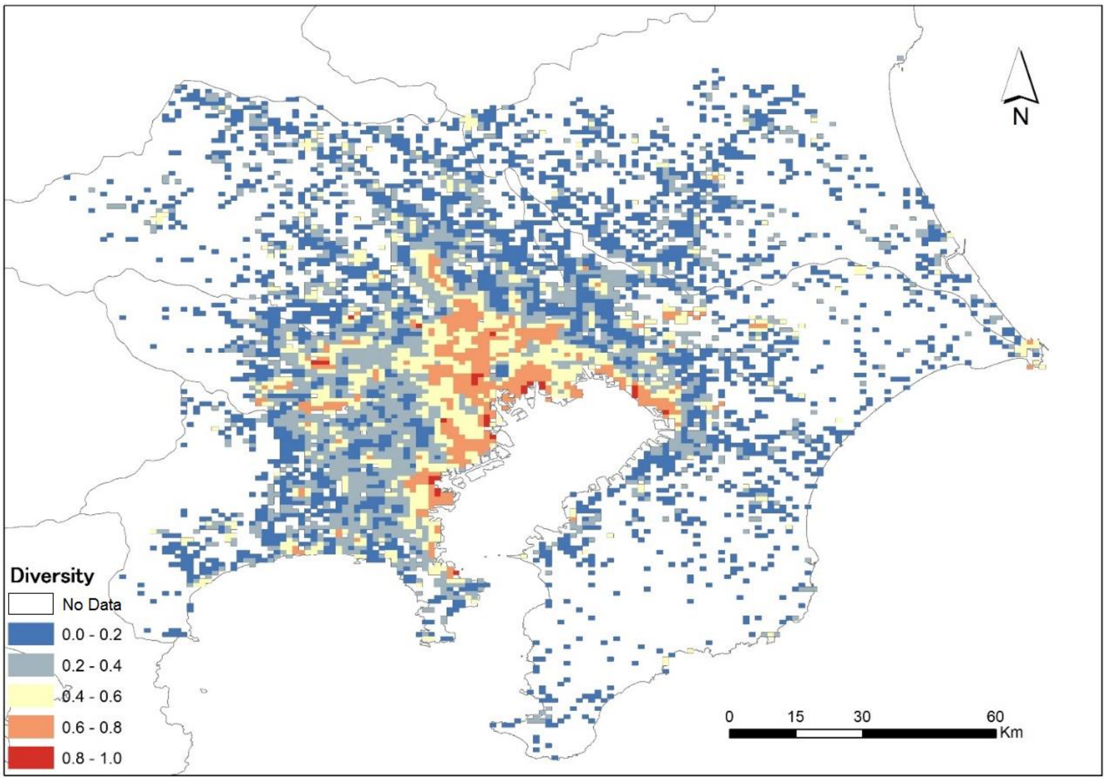

Figure 5-3: Land use diversity of TMA

5.1.4 Bus stops density

Results of the BSD (Fig. 5-4) showed that besides the areas close to the boundary of TMA, most areas owned at least 3 bus stops in each neighborhood context (1 km buffer). The majority of Tokyo city and Yokohama city had more than 6 bus stops in each neighborhood zone. This proved that the Tokyo city, as well as the Yokohama city had a complete bus service system to serve all the citizens regardless of the distance to the city center while in rural areas only residents living in places close to the railway lines enjoyed good accessibility to enough bus stops. The low BSD in some rural areas might cause a preference for local residents to use vehicles for daily movement and this could result in a lack of utilitarian walking in daily life.

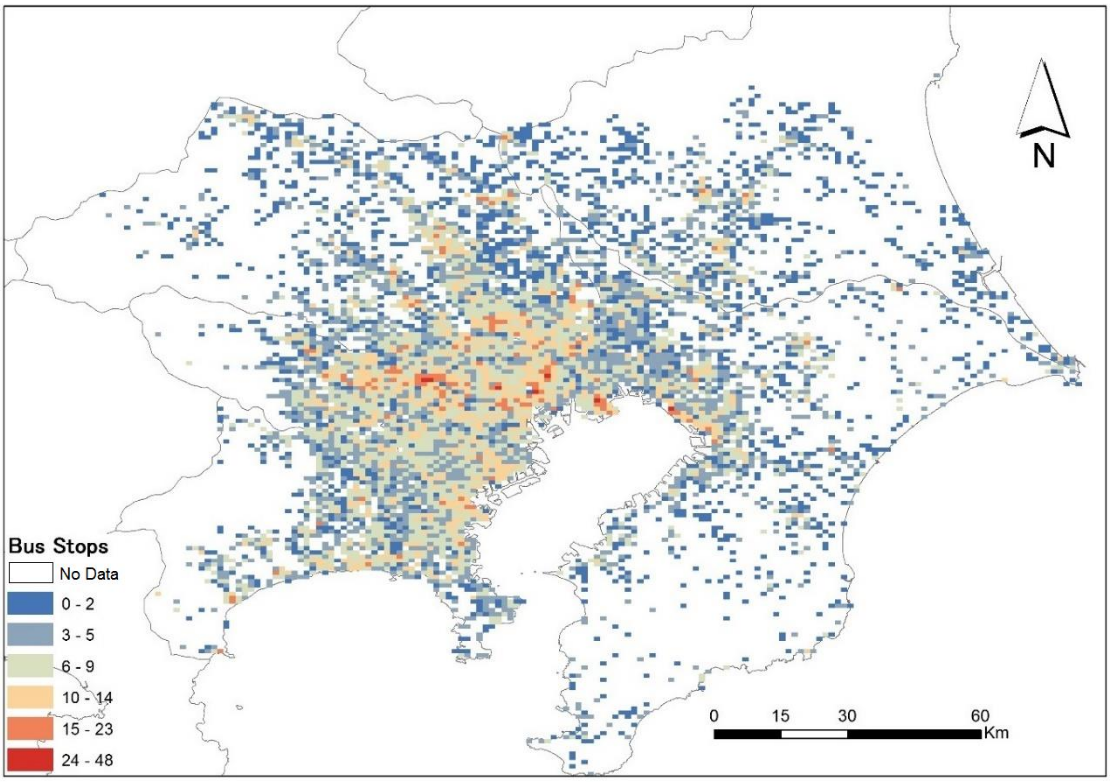

Figure 5-4: Bus stops density of TMA

5.1.5 Railway stations accessibility

Results of the RSA (Fig. 5-5) showed an amazing fact that almost all the residents living in Tokyo city or Yokohama city were able to arrive in the closest railway stations in 10 minutes by walking (a distance of 1 km). With the increase in distance to the Tokyo Station, regard as the heart of the railway transportation system in the metropolitan area, the RSA decreased to lower level. In some rural areas, residents had to move for over 5 km (some areas over 10 km) to reach the railway station. In this context, the reliance of residents on the railway would decline and this might result in the decrease of utilitarian walking behavior.

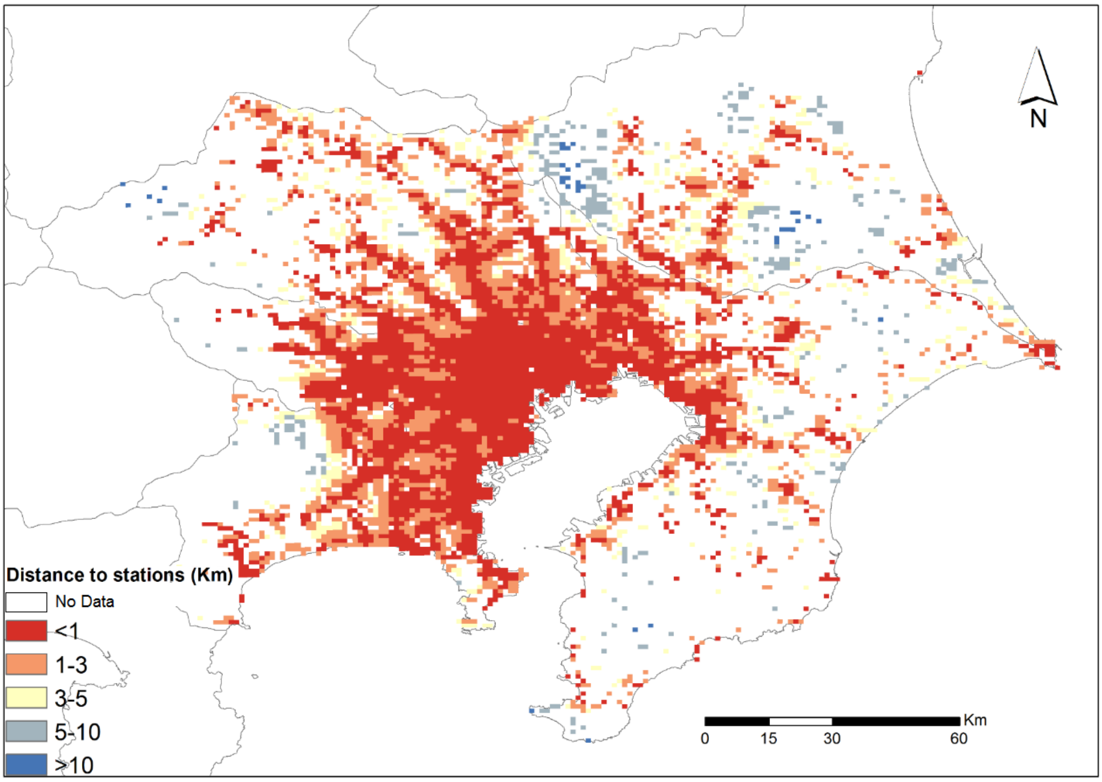

Figure 5-5: Railway station accessibility of TMA

5.1.6 Sightseeing spots accessibility

Evaluation results for SSA (Fig. 5-6) showed that in the central area of Tokyo and some rural areas in the prefectures of Saitama, Ibaraki and Chiba, the neighborhoods had a better accessibility to the sightseeing spots. In contrast, the neighborhoods in most of the suburban areas had a low level of accessibility to sightseeing spots. Sightseeing spots provided the potential destinations for recreational walking and it should be noticed that sightseeing spot was not only preferred by visitors, local people also intended to spend their leisure time there for walking or meeting friends. Since the sightseeing spots in an area were relatively stable, the protection of them were more critical from the perspective of increasing recreational walking level than trying to build new sites.

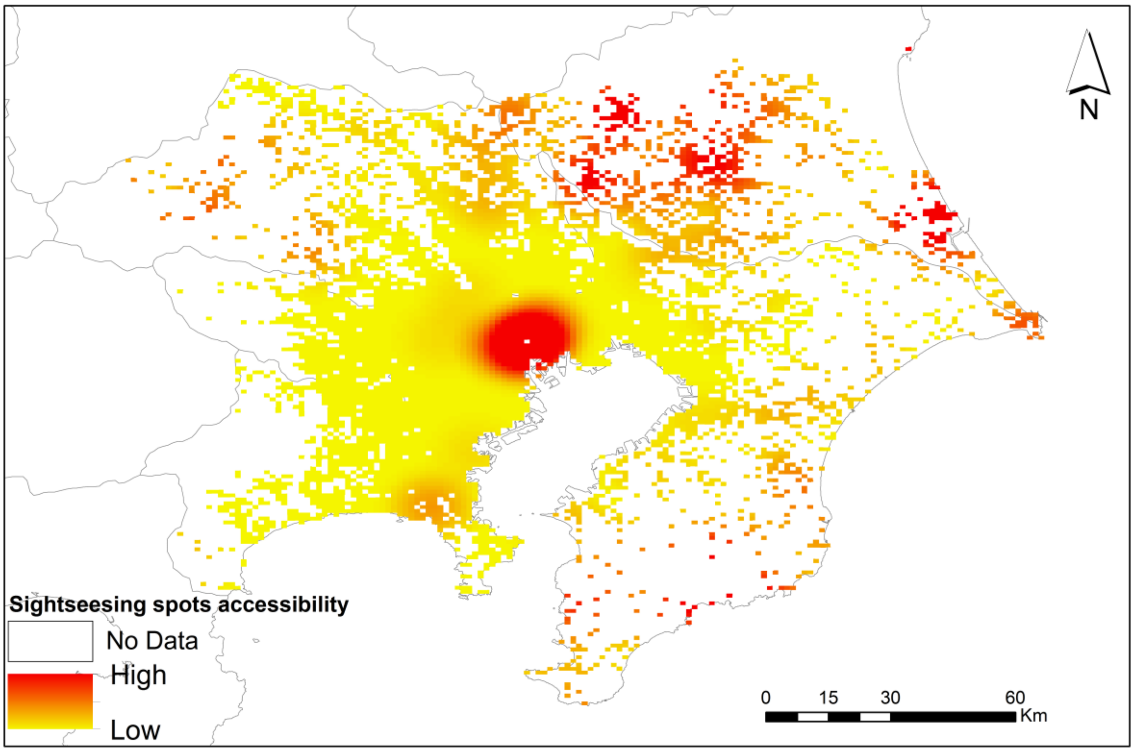

Figure 5-6: Sightseeing spots accessibility of TMA

5.1.7 Greenness density

The GD was represented by the average value of NDVI in the neighborhood scale. The values of NDVI ranged between -1 and 1 with the higher value represented a better condition of vegetation. The remote sensing data was derived from October so that the value could not be compared with the results derived from the image in summer seasons. The general pattern was that the city area of Tokyo and Yokohama had a lower value than those rural areas (Fig. 5-7). This result was typical as the city was relatively much more crowded than rural areas so that city areas didn’t have plenty of space for the vegetation. Besides, the result was quite smooth partly because of the low resolution of Landsat data. The difference for residents living in neighboring area in the level of GD didn’t have significant change.

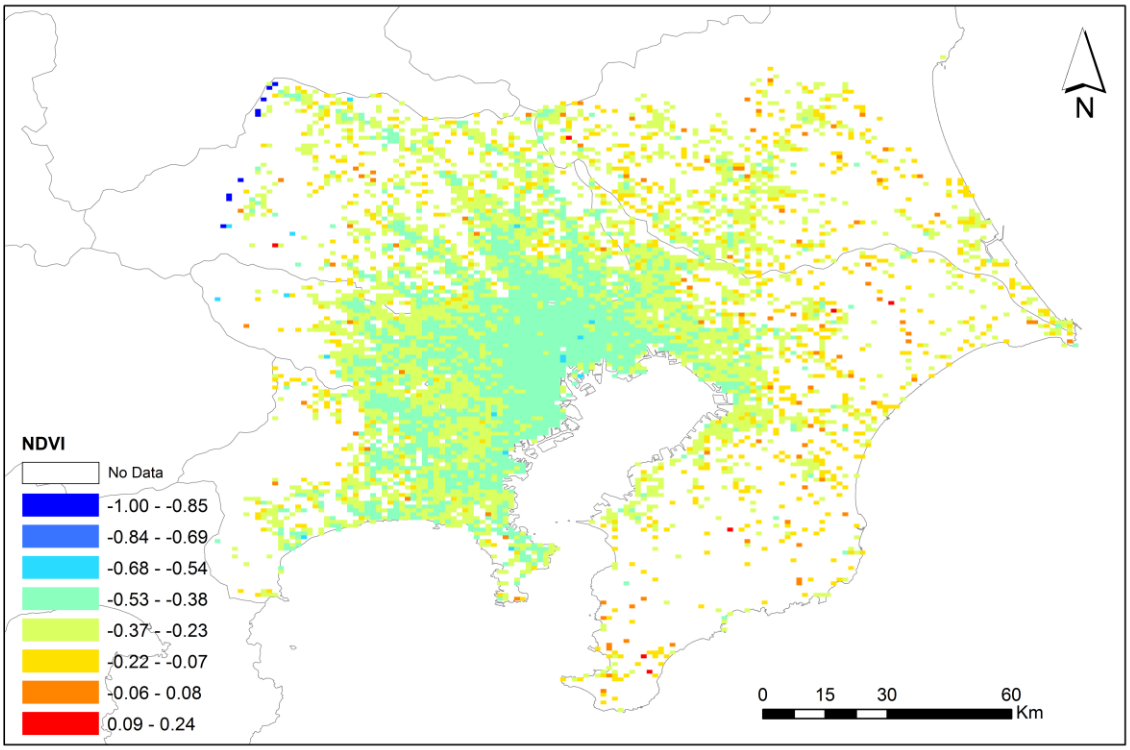

Figure 5-7: Greenness density of TMA

5.1.8 Parks density

PD showed an opposite result compared with GD (Fig. 5-8) that urban areas had a higher density of parks in the neighborhood while in some rural areas even no park could be found in the neighborhood scale. In another perspective, the difference showed a different requirement for residents living in urban and rural areas. Because of the high density of residential buildings, urban residents need public facilities like parks to relax in leisure time. On the other hand, the plenty of trees and forestry in rural areas reduced the necessity of the existence of parks for local people. However, it is also unfair to deny the effect of parks on attracting people to enjoy recreational walking even if they live in rural areas.

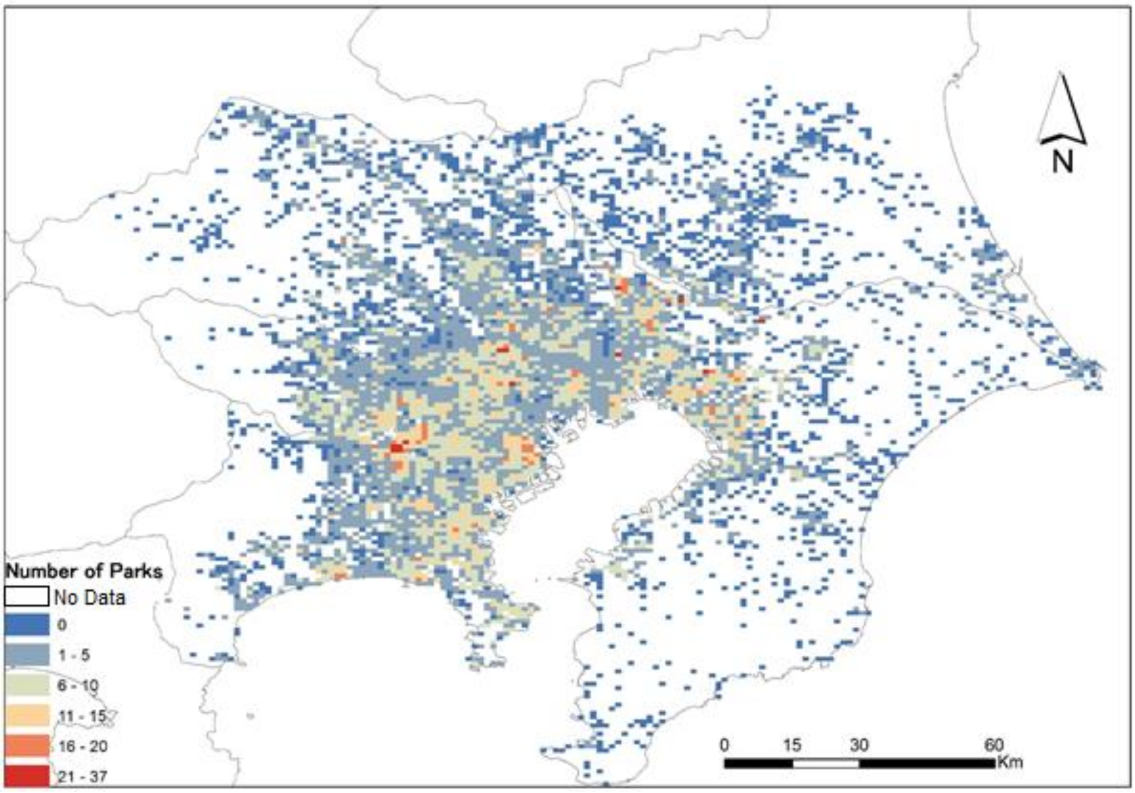

Figure 5-8: Parks density of TMA

5.2 Multiple regression analysis for selecting criteria to measure utilitarian walkability and recreational walkability

In order to decide which criteria were necessary for measuring utilitarian walkability and recreational walkability, the multiple regression analysis was processed with SPSS, version 20. Table 5-1 and 5-2 summarized the performance of models with different combination of criteria. From table 5-1 it was clear that when the number of variables reached five with the combination of SC, RSA, RD, LUD and BSD, the highest value of R appeared. As a result, these five criteria were selected in the process of measuring utilitarian walkability in the following chapter. However, it was needed to mention that the value of the R was still in a low level which implied no obvious correlation between the neighborhood environmental criteria and utilitarian walking time. So the purpose of this step is not to reveal the correlation but to find the best set of criteria for evaluating walkability. Table 5-2 summarized the performance of all the models related to the RWT and the best combination shown here included the criteria of PD, SC and GD with an R value of 0.306, which still represented almost no correlation. As a result, this three criteria were utilized for the calculation of recreational walkability.

Table 5-1: Model summary in multiple regression analysis related to utilitarian walking

Model	R	Std. Error of the Estimate (min)
1	.206	18.449
2	.225	17.854
3	.254	17.655
4	.304	17.405
5	.332	17.265
6	.324	17.316
7	.294	17.459
8	.253	17.701

1. Predictors: (Constant), SC
2. Predictors: (Constant), SC, RSA
3. Predictors: (Constant), SC, RSA, RD
4. Predictors: (Constant), SC, RSA, RD, LUD
5. Predictors: (Constant), SC, RSA, RD, LUD, BSD
6. Predictors: (Constant), SC, RSA, RD, LUD, BSD, PD
7. Predictors: (Constant), SC, RSA, RD, LUD, BSD, PD, GD
8. Predictors: (Constant), SC, RSA, RD, LUD, BSD, PD, GD, SSA

Dependent Variable: UWT

Table 5-2: Model summary in multiple regression analysis related to recreational walking

Model	R	Std. Error of the Estimate (min)
1	.183	7.087
2	.224	7.030
3	.306	6.967
4	.299	6.971
5	.241	6.997
6	.203	7.058
7	.181	7.096
8	.165	7.143

1. Predictors: (Constant), PD
2. Predictors: (Constant), PD, SC
3. Predictors: (Constant), PD, SC, GD,
4. Predictors: (Constant), PD, SC, GD, RD
5. Predictors: (Constant), PD, SC, GD, RD, SSA
6. Predictors: (Constant), PD, SC, GD, RD, SSA, LUD
7. Predictors: (Constant), PD, SC, GD, RD, SSA, LUD, BSD
8. Predictors: (Constant), PD, SC, GD, RD, SSA, LUD, BSD, RSA

Dependent Variable: RWT

5.3 Utilitarian walkability of TMA and its spatial patterns

The five criteria were merged together with the equal weight and the result was shown in Figure 5-9. Most of the high walkable (utilitarian walkability value: 4-5) areas concentrated on the 23 special wards of Tokyo and the Yokohama city, except for the Chu'o ward in Tokyo city as it was the central business area. Residents in these high walkable areas enjoyed a good accessibility to public transportation facilities including bus stops and railway stations. Because of this, residents there had high potential to have utilitarian walking for commuting to stations in daily life. The high diversity of land use here provided plenty of potential destinations for residents to walk for within the neighborhood scale. The complex road network here reduced the potential for people to move by a private car.

The medium walkable (utilitarian walkability value: 2-3) area appeared along the railway lines as well as the municipal lines between special wards of Tokyo and other prefectures. Residents here also owned a good accessibility to the public transportation facilities because of the fantastic public transportation service system in TMA. Considering the land use, these areas also had a high level of RD which could increase the possibility of having a utilitarian walk in the neighborhood for an appointment. However, compared to the high walkable areas, the SC and LUD were relatively low in these areas. In this context, the potential for utilitarian walking behavior within the neighborhood would decrease.

Low walkable (utilitarian walkability value: 0-1) areas scattered in the rural areas with the longest distance to the city center compared to the other categories. Residents here suffered a bad accessibility to the public transportation facilities including bus stops and railway stations, and it led to a high potential for local residents to use private vehicles for daily movement. The low residential density and land use diversity here reduced the chance for residents to reach a destination by walking since the potential destinations were far from their living neighborhoods. In general, the walkability map was related to the urban structure from the spatial perspective. It could be summarized that except for the central business district of Tokyo (the Chu'o ward), the utilitarian walkability of neighborhoods decreased when the distance to the city center increased.

The relationship between the average utilitarian walkability of residents and the distance from residence to city center was also checked (Fig. 5-10). In general, areas with a distance of less than 50 km to the city center had a higher utilitarian walkability (over 2.5) than the utilitarian walkability in outer areas. The 50 km distance was regarded as the boundary between urban and rural area so the results showed that residents in urban areas had a higher utilitarian walkability than rural residents. Besides, in urban area, the highest utilitarian walkability appeared in areas with a distance of 10 – 30 km to the city center while the urban core area only had a medium utilitarian walkability (average utilitarian walkability value = 2.56). The difference mainly came from the criteria of residential density and land use diversity. Considering the function of urban core area to the whole metropolitan area, urban core area tended to have less residential density and lower land use diversity than other urban or suburban areas since it was mainly composed of commercial land use. All the average values of utilitarian walkability in rural rings were less than 1.5 and a trend could be detected that with the increase of the distance, the value decreased. The low utilitarian walkability in these areas were caused by the low accessibility to public transportation as well as the low density of roads and buildings.

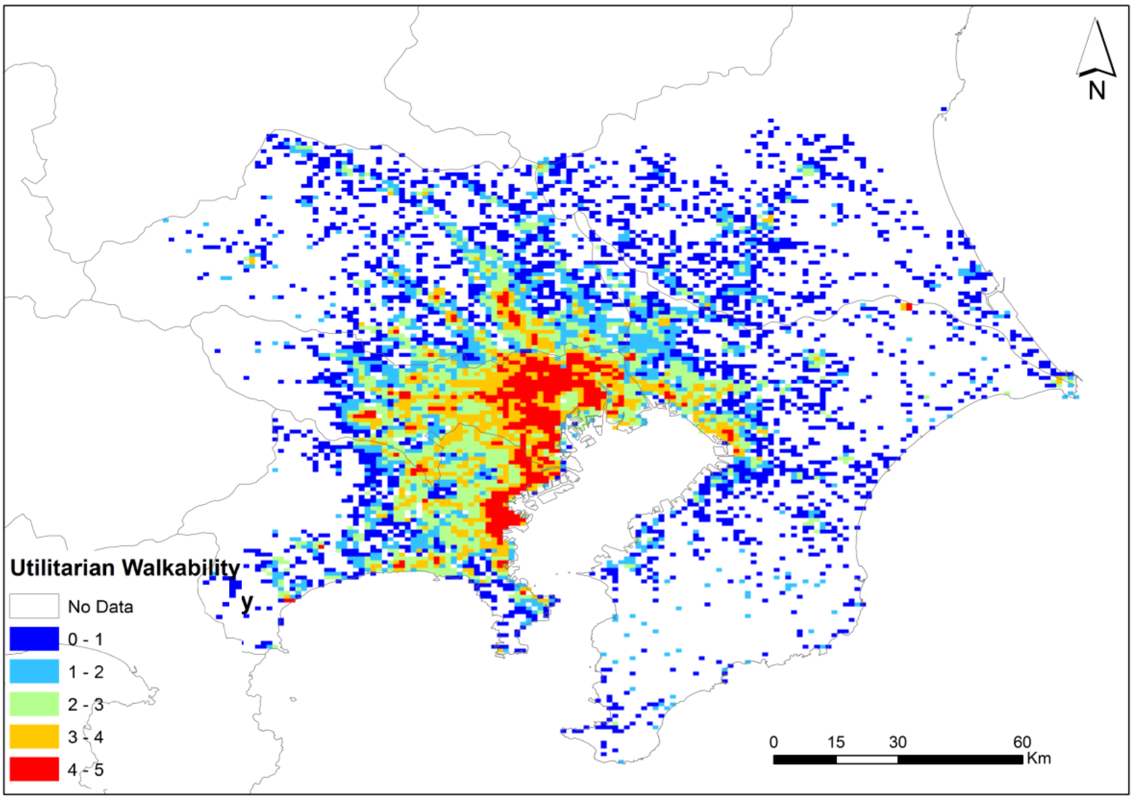

Figure 5-9: Utilitarian walkability of TMA

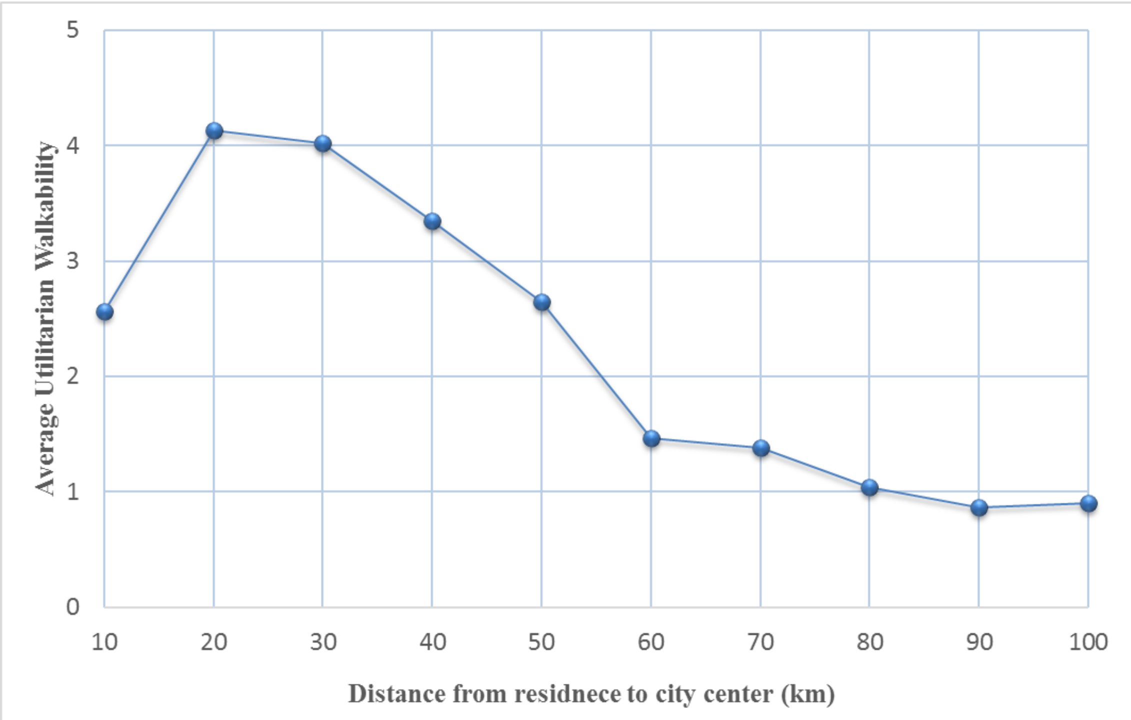

Figure 5-10: Relationship between utilitarian walkability and distance from residence to city center

5.4 Associations between utilitarian walkability and utilitarian walking behavior

By comparing Figure 3-3 and Figure 5-9, similar spatial patterns can be detected that residents in the rural areas had low utilitarian walkability in the neighborhood and low utilitarian walking time. On the other hand, residents in the urban areas, especially areas close to the city center, enjoyed high walkability and had more utilitarian walking time per day. The consistency between the evaluation results of utilitarian walkability and utilitarian walking time was also clear that the mean utilitarian walking time perfectly matched the utilitarian walkability level. Residents in the low walkable area had an average UWT of 30.56 min/day and with the increase of utilitarian walkability, the average UWT kept increasing until the peak (35.53 min/day) with the utilitarian walkability reached the value between 4 and 5 which indicated a high walkable area. The size of each part in the pie chart represented the proportion of residents living in areas belonging to each category. From this, it could be concluded that among all the respondents undertaken the Person Trip Survey in TMA in 2008, over 80% lived in neighborhoods with moderate or higher levels of utilitarian walkability while only 6.9% of the respondents lived in low walkable areas. With the average value of utilitarian walkability increased by 1, the average UWT increased by around one minute continuously from the lowest level to the highest level.

5.5 Recreational walkability of TMA and its spatial patterns

The three criteria (SC, GD, and PD) were merged together with the equal weight and the result was shown in Figure 5-11. The dominant category is level 1 (low walkable) which covered most of the rural areas far from the urban core of Tokyo. A high proportion of urban and suburban areas belong to the group of medium walkable area (recreational walkability value: 1-2). Besides, a very limited high walkable (recreational walkability value: 2-3) area could be found in TMA. Unlike the spatial patterns of utilitarian walkability, recreational walkability is not related with the public transportation rail lines. Since only three criteria were included in this approach and two criteria (GD and PD) of them had similar spatial patterns, the final results followed their patterns. In this case, more variables of neighborhood environment (such as traffic volume, safety, and lightness in the evening) related to recreational walking might be necessary to be included in the approach to make the results more reliable.

The multi-ring analysis was also processed for checking the relationship between the average recreational walkability of residents and the distance from residence to city center (Fig. 5-12). The results showed that residents living in places with a short distance to the city center (10 km – 30 km) had the highest recreational walkability while the real central areas did not have the highest recreational walkability. The difference came from the difference in greenness since the central area were composed of commercial land use and had limited areas for green spaces. All the areas with a distance of more than 50 km to the city center had a recreational walkability that less than 1 and as the increase of the distance, the value of recreational walkability decreased. The main reason is from the criterion of street connectivity that with the increase of the distance, the density of roads decreased.

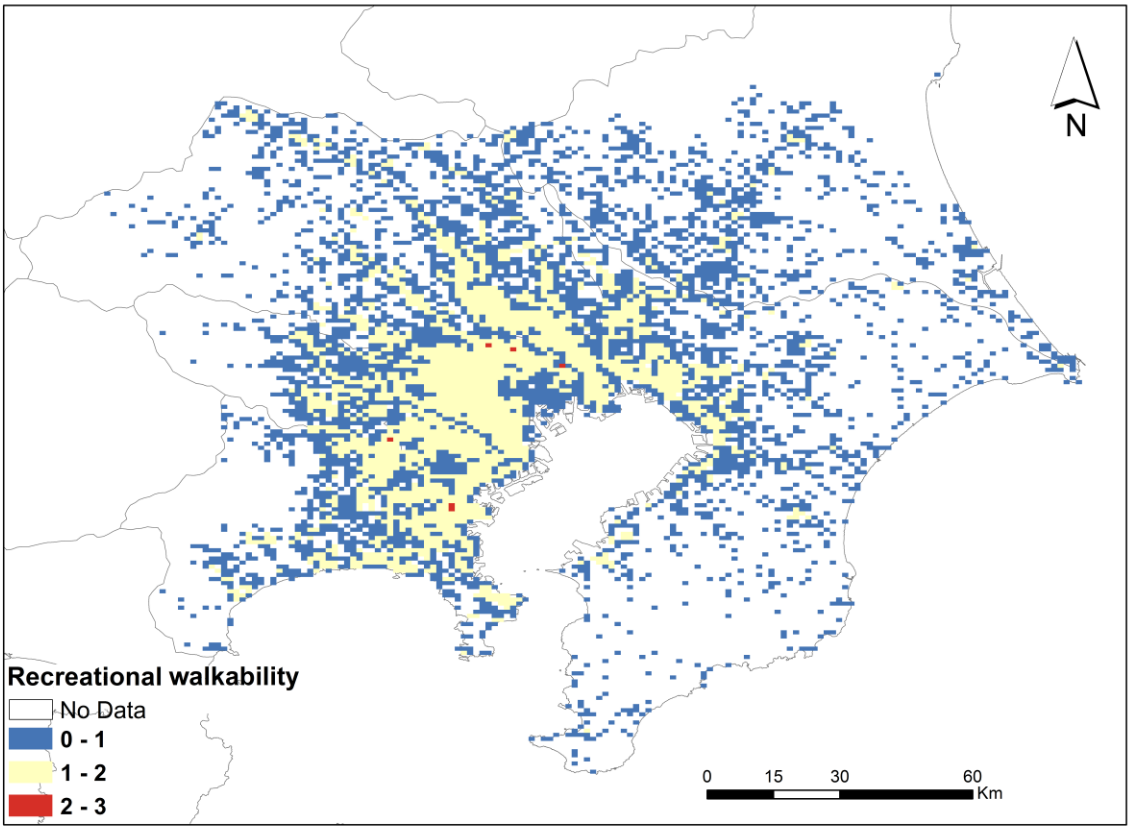

Figure 5-11: Recreational walkability of TMA

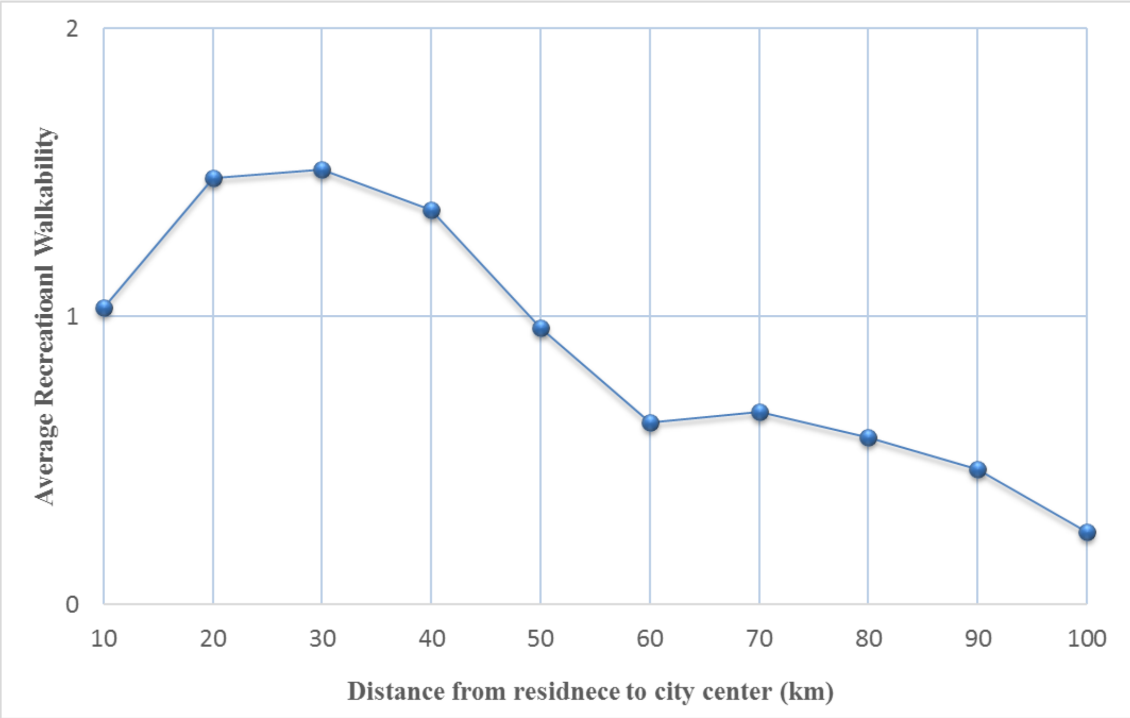

Figure 5-12: Relationship between recreational walkability and distance from residence to city center

5.6 Associations between recreational walkability and recreational walking behavior

In general, over 60 % of residents in TMA lived in neighborhoods with a low recreational walkability. They averagely spent 19.33 minutes per day in recreational walking. This amount also ranked in the last, with the highest average RWT of 23.17 minutes detected from people who lived in the high walkable area (recreational walkability over 2) and the medium amount of 20.08 minutes found in groups of people living in low walkable areas (recreational walkability value: 1-2). Besides, very limited areas were found to have a high recreational walkability in TMA (4.8 %) which indicated that the level of the three criteria included in measuring recreational walkability were relatively low in TMA, especially in rural areas. In conclusion, the results of average RWT and recreational walkability showed the consistency since with the value of recreational walkability increased, the average RWT also increased.

5.7 Effect of the neighborhood context on walking behavior

The multiple regression results showed almost no correlation between the neighborhood environmental criteria and the utilitarian and recreational walking. In order to improve the result, a case study with randomly selected 500 samples from the People Flow Data was done from the perspective of the location where the walking happens. Since all the criteria evaluated in this study had a boundary of the neighborhood zone (1 km), there is a necessity to extract only the walking behavior happened within the neighborhood context and compare the results with the utilitarian and recreational walkability to find potential relationships. The results of this case study (Fig. 5-13 and Fig 5-14) showed that both utilitarian walkability and recreational walkability had higher correlations with UWT (r^2 = 0.21) and RWT (r^2 = 0.27). The value reached a weak correlation level which implied the measured walkability could in some degree reflect the walking time of residents in each neighborhood zone. Compare with the results in the previous sub-chapters which didn't exclude the walking behavior happened outside the neighborhood zone, these results proved the importance of considering the location of the walking behavior referring to the neighborhood context.

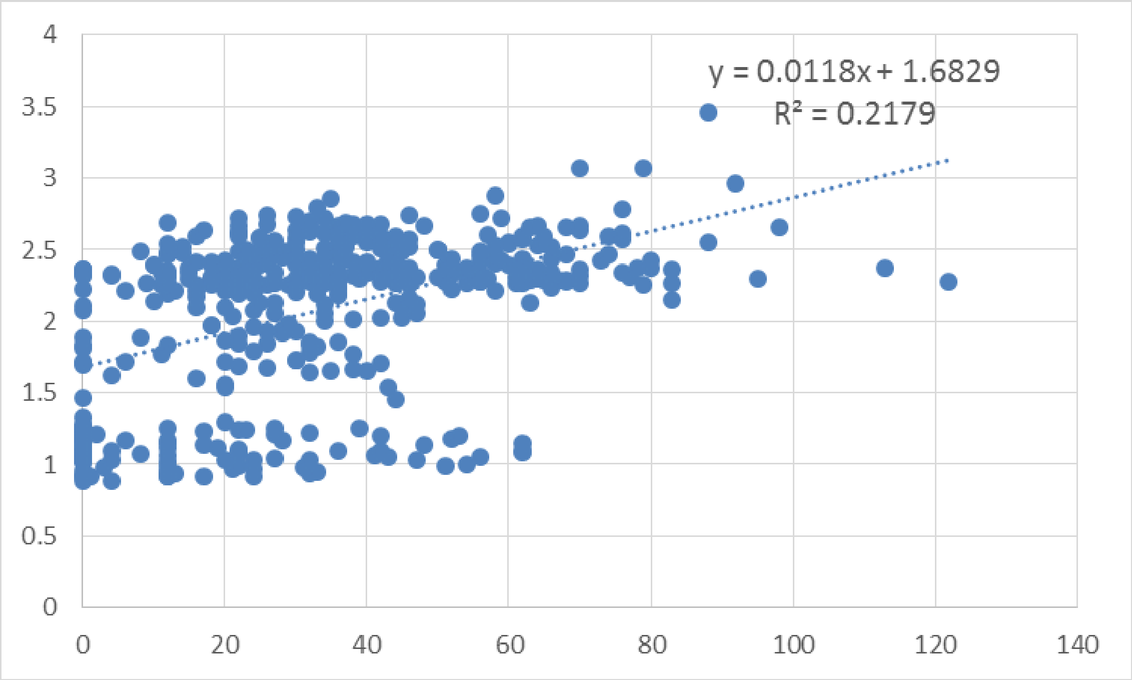

Figure 5-13: Correlation between UWT within neighborhood (X) and utilitarian walkability (Y)

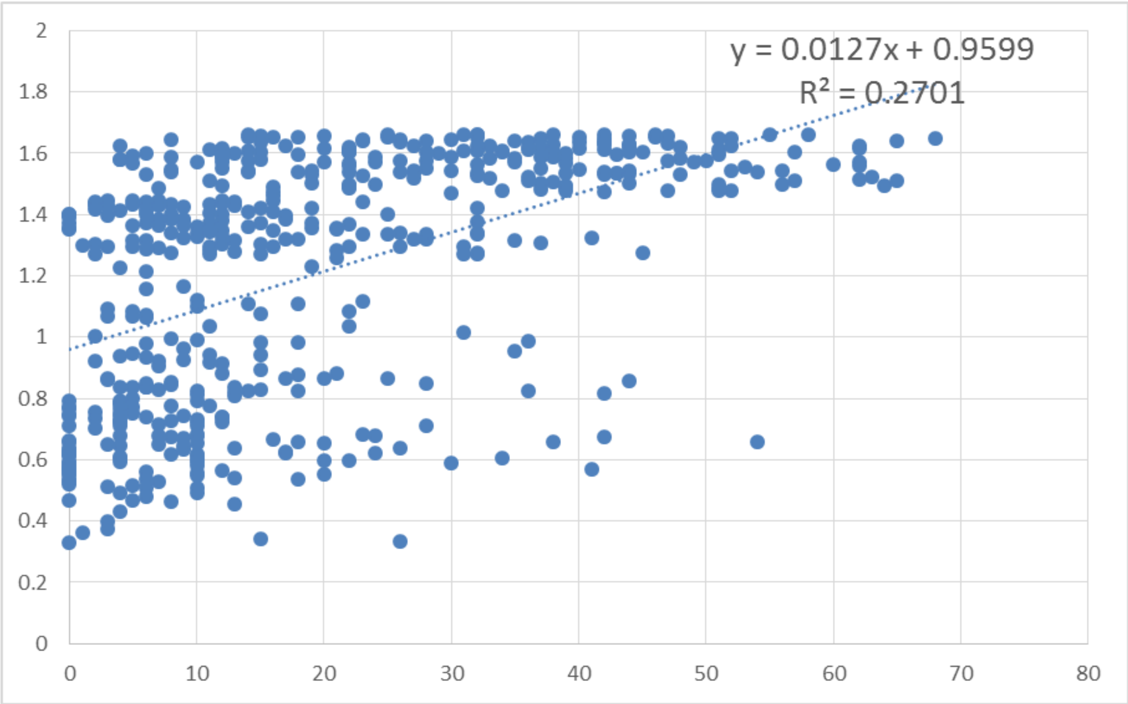

Figure 5-14: Correlation between RWT within neighborhood (X) and recreational walkability (Y)

5.8 Discussion

The main purpose of this chapter is to evaluate the utilitarian walkability and recreational walability based on different criteria and detect the potential relationships of the walkability with the results of walking time. In order to calculate utilitarian walkability and recreational walkability respectively, the multiple regression analysis was done to decide the most suitable combinition of criteria. Also the correlation value was low ($r^2 < 0.2$), the results showed that SC, RSA, RD, LUD and BSD were suitable for evaluating utilitarian walkability while SC, GD and PD were suitable for evaluating recreational walkability. The criterion of SSA, which was supposed to be related with recreational walking behavior, were found not necessary in evaluating both utilitarian and recreational walkability while SC was included in the evaluation of both two walkability. With the selected combination of criteria, the utilitarian and recreational walkability were measured in each neighborhood.

In general, utilitarian walkability and UWT showed consistency by comparing the average value. Similar consistency was also found between recreational walkability and RWT. These results proved the criteria selected for the evaluation were reasonable. All the 23 wards inside the Tokyo city except the central area had high utilitarian walkability. Considering the criteria included in the measurement, the high potential came from several aspects: 1) the Tokyo city was a dense area with high population density. As a result, the residential buildings and roads were also very dense in these areas and these two factor could promote utilitarian walking behavior; 2) the Tokyo city was highly developed so that plenty of different facilities were available in neighborhood scale. This provided potential for residents to have utilitarian walk; 3) the highly developed public transportation system made the public transportation facilities become potential destinations for local residents. Considering the high density of these facilities in Tokyo city, people had high potential to take a utilitarian walk to reach bus stops or railway stations. Besides, the low value of utilitarian walkability in the central area resulted from the most of these areas were occupied by commercial land use buildings. Most of the suburban areas had medium value of utilitarian walkability except for some city centers like the Yokohama city. The public transportation facilities were still densely allocated there and residential density here was also in high level. However the road network in these suburban areas were not as dense as the Tokyo city and also the number of daily life-related facilities were not less than the urban areas. As a result, the results in suburban area had a medium potential for utilitarian walking. Rural areas had the lowest potential for utilitarian walking because the residential buildings, roads, daily life-related facilities and public transportation facilities were all in a low level. In fact, because of these situations, most of the families lived in this area relied on vehicles for movement.

The results of recreational walkability was slimly different with the patterns showed in the results of utilitarian walkability. The urban and suburban areas were in the same level which meant that both of them had similar number of parks and street connectivity in the neighborhood context and the greenness level were also similar. The only contrast was with the rural areas. Because of the low population density, the number of parks as well as the street connectivity were limited there. Although rural areas usually had higher level of greenness, when combine all the criteria, these areas were still in the lowest level.

Another point need to be noticed is place where the walking happened. In the case study with 500 samples, the walking time were separated into walking time within the neighborhood context and other walking time in order to detect the neighborhood effect. The findings showed that all the results improved when only using the walking time within the neighborhood context instead of the total walking time. The correlation between utilitarian walkability and UWT within neighborhood reached 0.21 while in the case of recreational walking, the correlation between recreational walkability and RWT with neighborhood reached 0.27. These correlation values were positive when comparing with other studies in this field. Frank et al. (2005) found weak but significant correlations between the minutes of moderate physical activity per day with land use mix (r^2 = 0.15), net residential density (r^2 = 0.18), and intersection density (r^2 = 0.11). Carlson et al. (2015) developed a model to evaluate the neighborhood environment and they found a very small correlation (r^2 = 0.06) between the evaluation result of neighborhood environment with sedentary time. Ellis et al. (2015) found that among all the criteria, street connectivity is, at best, only weakly associated with time spent in active travel time (r^2 = 0.14). In this context, it is confident to say the correlations found in this study were enough to reflect in some degree the effect of ideal neighborhood environment on promoting people daily walking. These results proved the hypothesis that the measuring walkability might only affect the walking behaviors took place inside the neighborhood context.

Chapter 6

Conclusions

The study on the effects of personal attributes as well as neighborhood environment on people's walking behavior is popular in recent years as people pay more attention on personal health and walking is the simplest way to improve the personal level of physical activity, which is highly related to personal health. The main purpose of this study is to detect the effects of both personal attribute and neighborhood environment on utilitarian walking behavior and recreational walking behavior.

The TWT, UWT and RWT of residents in TMA were derived from the People Flow Data which also contained the personal attributes. In general, residents in urban areas had the highest UWT and RWT while residents in rural areas had the lowest UWT and RWT. The spatial patterns of UWT showed that residents in suburban areas had the similar level of UWT with the residents in urban area and the railway lines only had an influence on people's utilitarian walking. With the increase of the distance to the city center of Tokyo, the level of UWT had an obvious decrease trend while this kind of trend could not be detected when focusing on RWT. When summarizing the results from the perspective of personal attributes, including gender, age and occupation, it could be detected that all of these three attributes could affect the level of UWT and RWT. As a result, it is important to separate all the people into different groups based on personal attributes when analyzing the characteristics of people's walking behavior.

The multiple regression analysis was done with the results of walking time and neighborhood environmental attributes to determine the suitable sets of criteria for evaluating utilitarian and recreational walkability respectively. The results showed that the combination of residential density, street connectivity, land use diversity, bus stops density and railway station accessibility were the most suitable set for evaluating utilitarian walkability while the most suitable set of criteria for evaluating recreational walkability included street connectivity, greenness density and parks density. When focusing on utilitarian walkability, the results showed that residents in urban areas with a good accessibility to the city center had the highest potential for utilitarian walking behavior, followed by the residents in the urban core and rural areas. The results of recreational walkability was slimly different with the patterns showed in the results of utilitarian walkability. The urban and suburban areas were in the same level and rural areas were still in the lowest level. Residents in rural areas might have recreational walking within the neighborhood only because they want to walk in greenness since potential recreational destinations were limited there.

The results of evaluating utilitarian and recreational walkability had a consistency with the result of residents' utilitarian walking time and recreational walking time derived from the People Flow Data. Although more detailed and deeper statistical analysis might be necessary, the current results reflected that people living in high utilitarian walkability areas really had more average utilitarian walking time and this is also true when checking the relationships between recreational walking behavior and recreational walkability.

Besides the findings of the associations, this study also released the maps of eight neighborhood attributes related to walking behavior, utilitarian walkability, recreational walkability, average UWT and RWT in TMA. These maps showed the spatial patterns similar to the urban structure. Previous studies mostly concentrated on a micro scale, but the findings here showed a possibility of comparing the neighborhood environment from the perspective of the whole urban structure.

The originalities of this study mainly came from the separation of walking behavior based on the purpose and the method for handling People Flow Data and the neighborhood environment-related data. Considering the big amount of the People Flow Data, the findings in this study could be more trustful. In addition, the widely-separated spatial location of the samples provided the possibility to link the walking and walkability patterns with the urban structure, which was a very rare approach that could not be found in previous studies in this field. The other originality was the buffer analysis based on individuals. Unlike the common approach which evaluates the neighborhood environment first and then assigns the value to the points fallen into each area, this study created a 1 km buffer for individuals and define this buffer as the neighborhood context. With this approach, the scale of each person's neighborhood could be more accurate and it increased the possibility to find trustful relationships between neighborhood environment and walking behavior.

Another point that needed to be concluded was the comparative study of two different types of walking behavior. Unlike most of the studies in this field, the author employed two sets of criteria for evaluating effects of neighborhood environment on utilitarian walking and recreational walking respectively. When detecting the effect of personal attributes, the analysis was also separated into the two categories of walking. The results in this study proved the value of studying effects separately based on the type of the walking behavior. This comparative study approach was strongly recommended by the author to be applied to other related studies.

The GIS-based objective measurement for neighborhood environment walkability seems to be more reliable than the perceived subjective measurements if the accuracy of the spatial data is acceptable because participants' perception of their neighborhood may vary even if they live in the same place. With the increasing computing capabilities, the GIS-based objective measurement provides a considerable opportunity to develop more accurate measures of the neighborhood environment. This study showed one standard way of interpreting related spatial data together for the evaluation and it also proved that GIS is suitable for handling big spatial data. With the technical developments in computer science and the increase of available open data sources, the GIS-based objective measurement is supposed to behave better in the future.

Limitation existed in this study. The eight criteria selected in this study might not be enough and including some other variables might improve the results. Although the consistency can be found by comparing the evaluation results of walkability and walking time, some areas such as the Chu'o ward showed mismatched patterns. Further study is needed for adding new variables to check and improve the results.

Overall, this study revealed the effects of both personal attributes and neighborhood environment on peoples' walking behavior. The evaluation of neighborhood environment reflected the reality and the results can be utilized by both urban planners and transportation network designers for building a more walkable city. Future studies are encouraged on deeper statistical analysis of the relationships among personal attributes, neighborhood environment, and residents' walking behavior.

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