USING ACCESSIBILITY TO EVALUATE THE BENEFITS OF A BUS RAPID TRANSIT LINE: A CASE STUDY IN HANOI

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FEBRUARY, 2014

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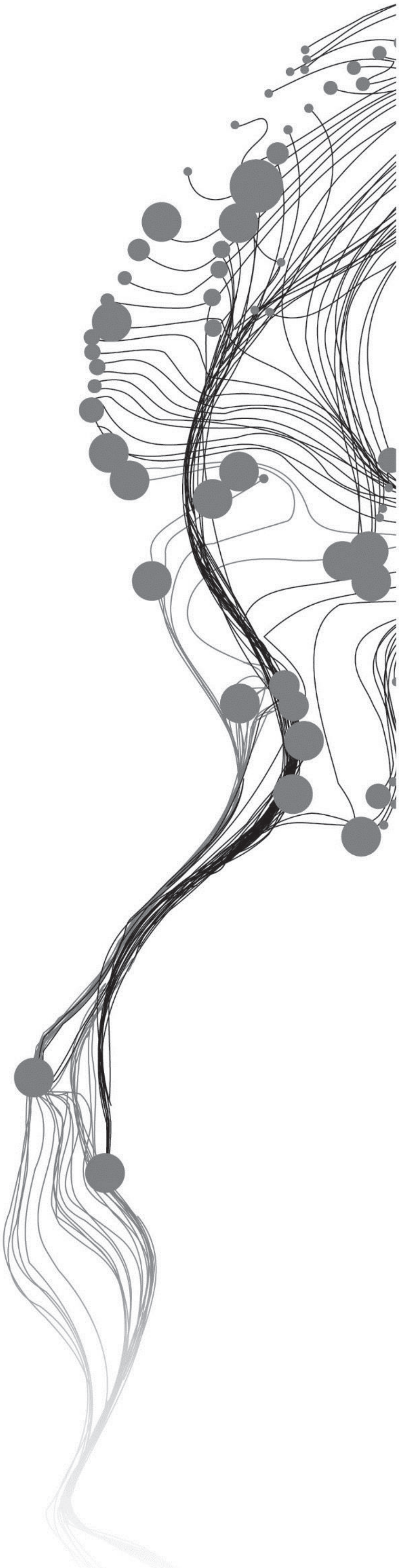

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ABSTRACT

As the capital of Vietnam, Hanoi city has been undergoing rapid urbanization associated with fast economic growth, and the trend is expected to continue further. However, the transportation in Hanoi city is currently dominated by motorcycles which cover the majority of travel needs while the public transportation just got a little share of the travel needs. This kind of transport structure may cause the negative effects such as traffic congestion, traffic accidents, environmental problems, etc. In order to change the share of private transport use and promote the use of public transportation in Hanoi city, A Bus Rapid Transit (BRT) line is proposed in Hanoi city. But whether this BRT line could really bring benefits to Hanoi city and what kind of benefits this BRT line may bring is not clear.

Accessibility, as an important spatial characteristic and a significant link between transportation and land use, plays a key role because it measures the end benefit of this integration(Sten Hansen, 2009). The purpose of this research is by using accessibility as the indicator for evaluating the benefits of BRT line in Hanoi. Three accessibility measures: Weighted Average Travel Time Measure, Potential Accessibility Measure and Competition-based Accessibility Measure are described and utilized respectively to see the contribution of the BRT on accessibility perspective. Three transport scenarios are tested to compare the current accessibility situation with the future accessibility situation after BRT line is constructed. The study firstly focused on the whole urban Hanoi, then limited to a service area along the BRT corridor to explore the accessibility changes caused by BRT line. The results indicate that the influence of BRT line to the whole urban Hanoi is limited in terms of accessibility. But it can make accessibility improvements on the areas along the BRT corridor when compared with the original public transport system. Besides, the BRT line may not change the predominant transport role of motorcycles in Hanoi city in the near future, but it can promote modal shifts from motorcycles to public transport.

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1. INTRODUCTION

1.1. Background

As the capital of Vietnam, Hanoi city has been undergoing rapid urbanization associated with fast economic growth, and the trend is expected to continue further. However, basic infrastructure services in Hanoi, especially the transport system are facing the problems of keeping up with rapid economic growth. Limited road networks, widespread traffic congestion and the missing of primary links in the City's road networks are the dominant problems in the current Hanoi infrastructure construction (World Bank, 2007). As reported in 2007 by ALMEC Corporation (2007) in HAIDEP project, transportation in Hanoi is currently dominated by motorcycles which cover the majority of travel needs while the public transportation just got a little share of the travel needs. This contributed to a strange phenomenon that Hanoi has the highest percentage of private transportation usage and the lowest percentage of public transportation usage among all Asian capitals. This kind of transport structure will make the traffic more congested and the speeds of other modes would be influenced by the behaviours of motorcycles. It is reported that in 2011, there were several million units of motorcycles and such a large number may leads to transportation problems such as traffic accidents or traffic congestion (Tran et al., 2012). Besides, severe environmental problems like the substantial emission of air pollutants and climate forcers are believed to be caused by a fleet of over two million motorcycles (Oanh et al., 2012). Therefore, to change the share of private transport use and promote the use of public transportation in Hanoi city is a potential measure to alleviate the negative impacts which the motorcycles could bring.

The Hanoi municipality has long recognized the importance of increasing the use of public transport services which could improve the urban mobility and bring benefits to Hanoi from social and environmental points of view. A Bus Rapid Transit (BRT) line running through the centre of urban Hanoi will be constructed. This BRT line are expected to bring benefits to the people of urban Hanoi or at least the people living in the corridor along the BRT line such as the reduction of travel cost and travel time, the reduction of fuel consumption and greenhouse gases emission, the mitigation of traffic congestion, and also the improvement of living environment. Besides, compared to other modern public transport, BRT system has advantages like fast delivering, comfortable and cost-effective urban mobility as well as rapid and frequent operations (Filipe & Macário, 2013). However, whether the proposed BRT line will really bring benefits to Hanoi and if so, what kinds of benefits the people in Hanoi could get? The donor of BRT line, World Bank, expects many benefits from this traffic line including modal shift from private transport to public transport, reduction of traffic congestion, improvement of living environment, etc. But this requires suitable measures or indicators to evaluate the benefits of the BRT line.

A variety of indicators had been applied for evaluating the benefits of a BRT system. Some of the traditional indicators focused on the benefits that BRT systems would bring to the mobility improvement where the transport infrastructure are measured by indicators such as improved connectivity, travel time, speeds and fuel savings (Tiwari & Jain, 2012). While more common ways are measuring BRT system with its operational efficiency, technical performance and cost issues (Deng & Nelson, 2013). Besides, there are also some evaluation index utilized for measuring BRT system such as influence to social economy, influence to traffic function, or influence to environment and the influence to resources utilization (Weihua et al., 2005). Due to the actual conditions and the specific characteristics, there is a need to select suitable indicators for measuring BRT system in Hanoi.

1.2. Research Problems

Accessibility, as an important spatial characteristic and a significant link between transportation and land-use, plays a key role because it measures the end benefit of this integration (Sten Hansen, 2009). It is a performance indicator for assessing transport policies, sustainable development and also the density and spatial distributions of urban people and activities (Ha et al., 2011). As a widely used indicator for evaluating the transport system and how well the transport system is integrated with the land use. Accessibility is often applied at macro scale for the whole city or large regions (Li & Shum, 2001), or at micro scale at individual level (Mateos et al., 2012). Although accessibility is widely applied as an important indicator in transport field, there are still few studies on using accessibility to evaluate the benefits of a BRT line.

Accessibility to jobs in the city of Hanoi would be influenced by the construction of the BRT line. When considering accessibility, transport could have impact on the relationship between the number of accessible job opportunities and the total number of work force (Suescun & Hernandez, 2012). Through the measuring of the job accessibility level with the integration of BRT line, valuable feedbacks could be provided to the Hanoi policy makers in the future transport planning. This research will compare the difference to job accessibility that BRT line may bring, thus evaluate the benefits of BRT line.

1.3. Research Objectives

1. General Objectives:
Using accessibility to evaluate the benefits of a Bus Rapid Transit line in Hanoi city.

2. Sub-Objectives:
Sub-objective1: To build accessibility model for evaluating the benefits of the BRT line.
Sub-objective2: To evaluate and compare the current transport situation with the future transport scenario after BRT line is constructed on accessibility perspective.
Sub-objective3: To give suggestions to urban planners and decision makers in Hanoi on how to improve the construction of the BRT line in the future.

1.4. Research Questions

The research questions listed below related to the three sub-objectives:
Sub-objective 1: To build accessibility model for evaluating the benefits of the BRT line.
1) How is BRT evaluated in literature? What indicators have been used?
2) Whether job accessibility can be used as an indicator in this case?
3) What are the suitable accessibility measures that can be used for evaluating the benefits of the BRT line in Hanoi? Which accessibility model that can be applied in this case?

Sub-objective 2: To evaluate and compare the current transport situation with the future transport scenario after BRT line is constructed on accessibility perspective.
4) What are the structure and distribution of residential locations and job locations?
5) What are the transport scenarios for analyzing accessibility before and after the construction of BRT line?
6) What are the difference in levels of job accessibility in these scenarios and how to interpret these results?
7) What kind of changes may BRT line bring to the usage of motorcycles in Hanoi?

Sub-objective 3: To give suggestions to urban planners and decision makers in Hanoi on how to improve the construction of the BRT line in the future.
8) Which improvement could be made to improve the construction for the BRT line?

1.5. Conceptual Framework

Figure 1 is a general conceptual framework for getting the objectives of the research. Three elements play an important role for measuring job accessibility: transport, workers and jobs. Each element has spatial and non-spatial interaction with each other and all three elements combine to influence job accessibility. As a link between workers and jobs, the spatial distribution of transport infrastructure ensures the efficient connection between residential locations and job locations, and the non-spatial elements of the transport system also largely contribute to the variation of mobility provision (Cheng & Bertolini, 2013). Public transport (bus and BRT) and motorcycles are two main types of transport which the travel time and the choice of travel modes play a vital role in people's choice of work. The job accessibility under current transport condition will be compared with the job accessibility of the future transport condition after BRT line is constructed. Finally, benefits of BRT line in Hanoi will be evaluated in terms of accessibility, and further suggestions and lessons for BRT construction could be drawn from this research.

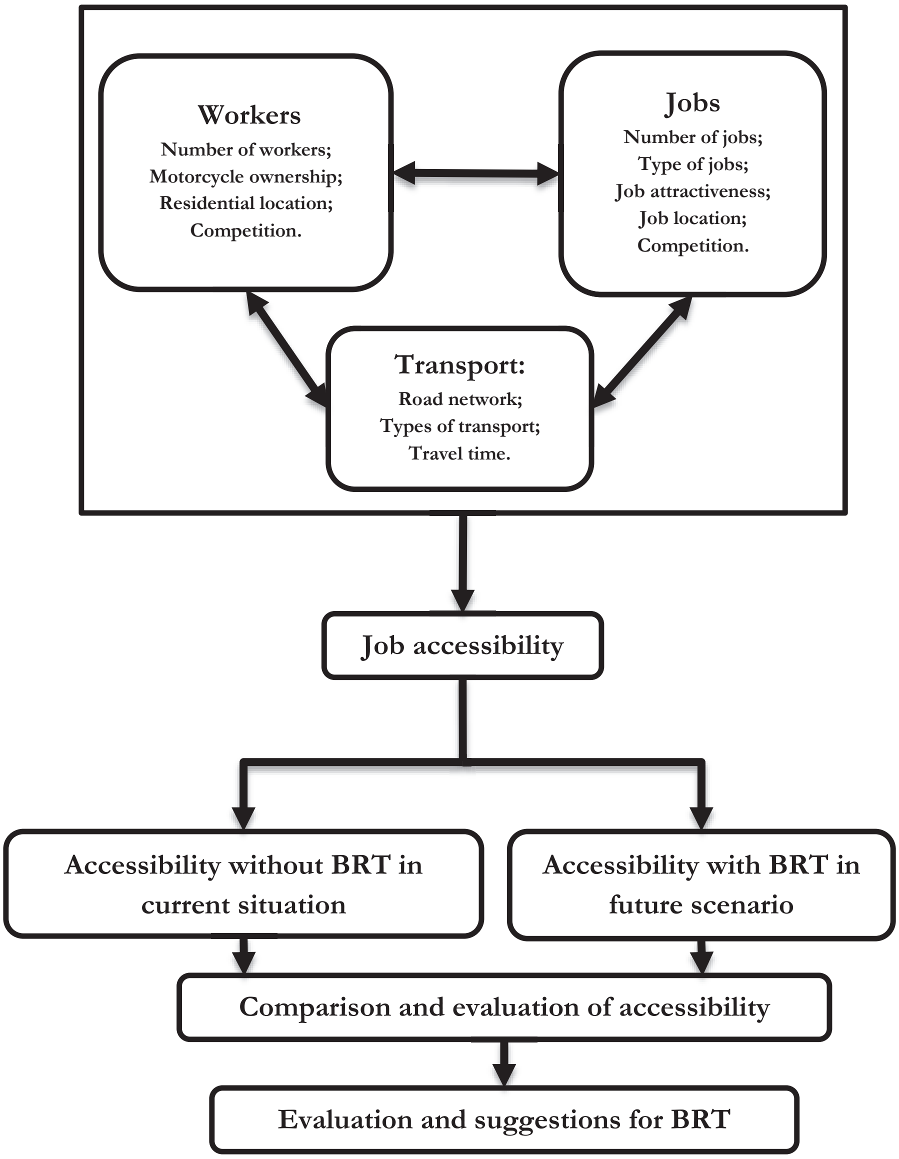

Figure 1 Conceptual Framework

1.6. Research Design

1.6.1. General Research Methods

The research methods and steps should be closely related to the research objectives. The brief description of research steps are:

1) A comprehensive literature review on the evaluation of BRT especially the application of accessibility on the evaluation of BRT. (Question 1)
2) Analyze the possibility that job accessibility can be used in this case. (Question 2)
3) Choose suitable job accessibility measures and define corresponding accessibility model. (Question3)
4) Explore the data and define the distribution of residential locations and job locations. (Question4)
5) Construct transport scenarios before and after the construction of BRT line for the accessibility model. (Question5)
6) Apply the accessibility model in the constructed scenarios to get corresponding accessibility results. (Question6)
7) Base on the accessibility results, analyze what kind of changes the BRT line may bring to the Hanoi. (Question7)
8) The conclusions and suggestions base on the accessibility results. (Question8)

1.6.2. Research Phases

To achieve the research objectives, there are five major research phases planed in the research process.

Phase 1: Problem Identification

This phase is mainly for the selection of job accessibility measures. The selection of job accessibility measures is based on a large amount of related literature reviews and the testing of the existing data. The proposed steps are:

- Have an overview of the study area, which is the urban Hanoi, especially focus on the socio-economic factors such as population or jobs, and infrastructure parts.
- Perform the basic data analysis and select the useful data and parameters which could be utilized in the research process.
- Have an overview of the existing accessibility models, select and develop the modelling framework of the job accessibility model to be used.

Phase 2: Data Preparation

The job accessibility analysis is based not only on the accessibility model itself, but also on the road networks. Therefore, this phase includes a preparation of residential data and job data. Besides, build road networks and set network property are also key assignments in this phase. The main tasks are:

- Base on the available data, find approaches to define spatial distribution of population data and employment data.
- Base on the infrastructure and transport conditions in the city of Hanoi, build road networks for the accessibility modelling use.
- Prepare data and parameters for accessibility models.

Phase 3: Scenario Preparation

Before the construction of BRT line, the main travel modes in Hanoi city for people to go to work are walking, bus and motorcycle. While after the BRT line is constructed, there may be certain proportion of modal shift from motorcycles to BRT. Therefore, different transport scenarios are required in this case for comparing the changes of accessibility. The proposed transport scenarios are displayed in Table 1 below.

Table 1 Transport Scenarios

Scenarios (Combination of travel modes)	Explanation
Motorcycle	Ride motorcycles to work
Walking Bus	A combine of walking and bus to work
Walking Bus BRT	A combination of Walking, Bus and BRT to work.

Phase 4: Model Formulation

After the preparation of the data and the corresponding parameters, the following step is to find a suitable way to implement the developed model in ArcGIS. The selected accessibility measures will be applied to calculate the accessibility values respectively based on different transport scenarios.

Phase 5: Results Analysis

The job accessibility analysis could be performed based on the accessibility results of different scenarios. Afterwards, there will be an evaluation of how the BRT corridor would influence the transport system and urban form in Hanoi. Several steps could be proposed as below:

- Job accessibility analysis based on the developed accessibility model.
- Interpretation of the analysis results.
- Evaluation of the job accessibility in the city of Hanoi.
- Evaluation of the benefits of BRT line in Hanoi.

1.7. Structure of Thesis

Chapter 1 Introduction

This chapter provides a brief introduction to some essential issues of the study, including background, research problems, research objectives, research questions, conceptual framework and the research design.

Chapter 2 Study Area and Data Analysis

A comprehensive study of the Hanoi base on related literatures and gives a general description Hanoi city especially focus on transportation part.

Chapter 3 Literature Review

A review of how previous researchers evaluate BRT system, and the related accessibility models, summarizing their advantages and limitations. Besides, accessibility measures for the research are chosen in this chapter.

Chapter 4 Methodology

This chapter introduces the methodology for preparing socio-economic data and transport data as well as the accessibility measures.

Chapter 5 Accessibility Results and Analysis

The results of the accessibility performance will be analysed in this chapter, along with the evaluation of the BRT line. The research first focus on the whole urban Hanoi, and then limit the study area into the service area along the BRT corridor.

Chapter 6 Conclusions and Recommendations

The conclusions and some remarks will be summarized in this chapter and some suggestions base on the limitation of the model will be given.

2. STUDY AREA

This chapter provides a brief description of Hanoi city, especially focus on the transportation of urban Hanoi.

2.1. Overview of Hanoi

Hanoi, as the capital of Vietnam, is the second largest city in the country. The city lies in the north-western part of the Red River Delta where the red river goes through from the eastern part of the city. Hanoi has roughly 6.5 million inhabitants over 3.4 square kilometres. It becomes the political, economic as well as cultural centre of the country since 11 AD. Besides, the special geographic location makes Hanoi the most important hub of communications as well as the largest harbour in Northern Vietnam.

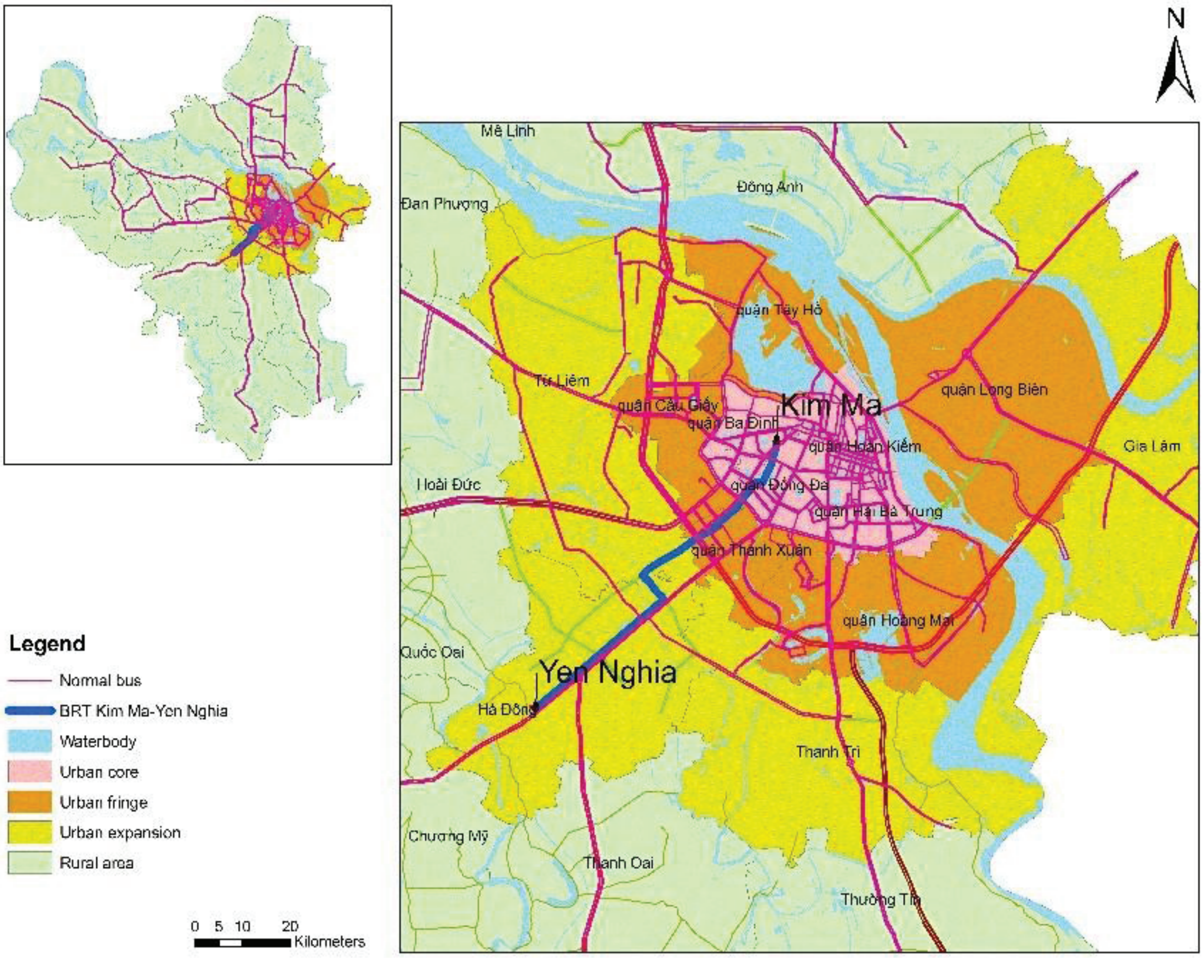

Figure 2 Location of BRT in Hanoi

Figure 2 is a map demonstrates a brief city structure of Hanoi and the geographic location of the proposed BRT line, which goes from urban core of Hanoi to the urban expansion areas. Figure 3 shows the exact study area of this research in urban Hanoi and the urban land structure. In the study area, urban lands are grouped into three parts, which is urban core, urban fringe and rural areas. In the core city centre, most of the lands are urbanized and roughly half of the city centre is occupied by residential and commercial locations while many institutional companies are concentrated in this core areas. Rural-use lands and residential areas dominates majority of the urban fringe while commercial areas only shares a little usage. Meanwhile, the population density map (Figure 4) in urban Hanoi demonstrates that the high population areas are concentrated in core city centre. These reflect the fact that although core city centre of Hanoi has very limited land size, but most of the social and economic functions as well as population are concentrated in this area which demonstrates a mono-centric urban form.

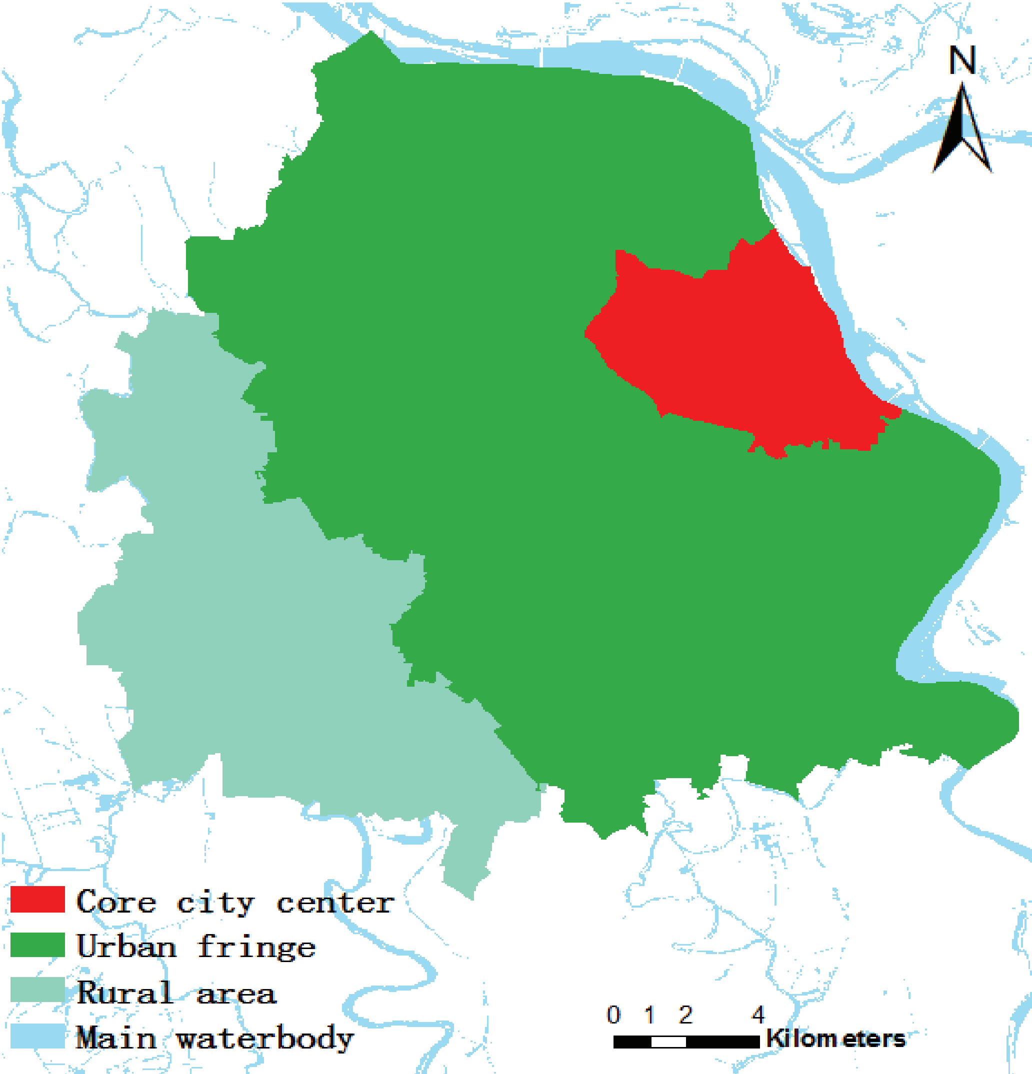

Figure 3 Classified Urban Areas of Hanoi

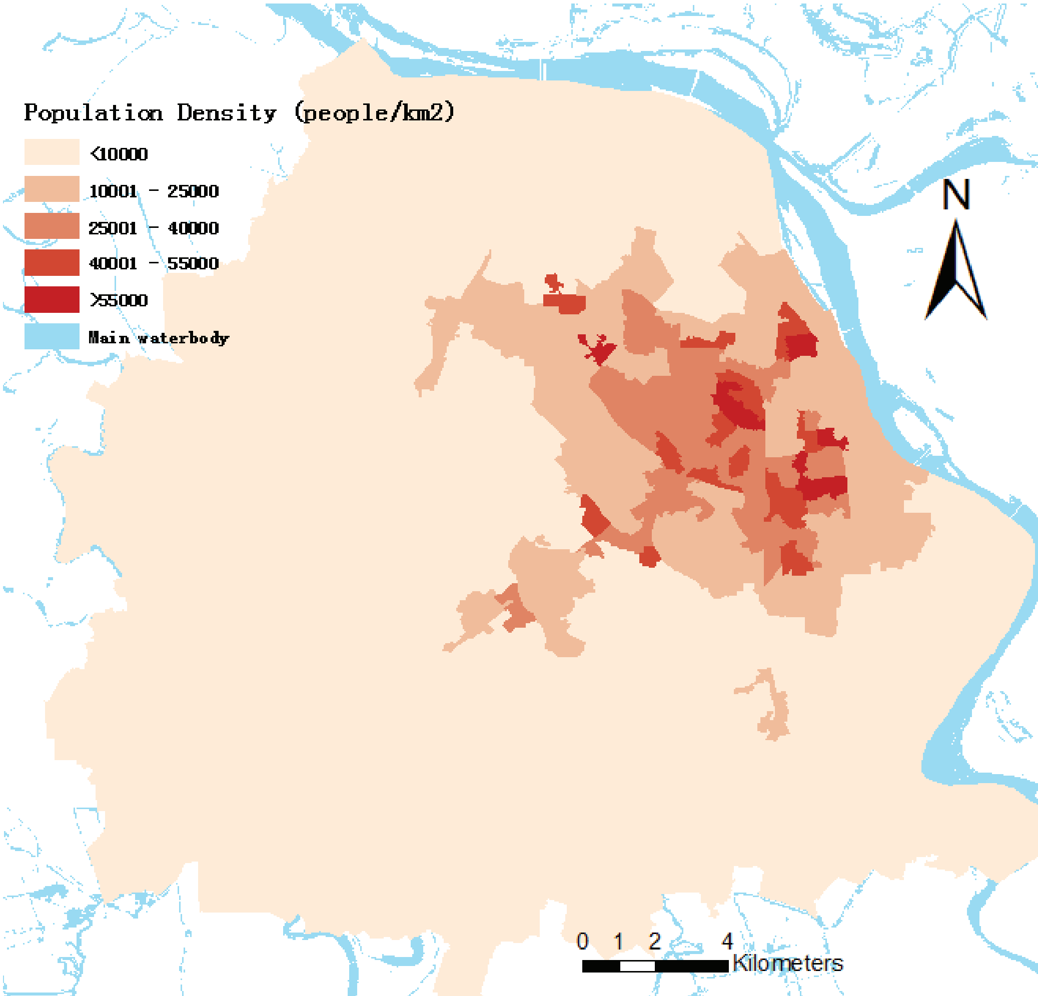

Figure 4 Population Distribution of Urban Hanoi

2.2. Urban Transportation of Hanoi

The transport system in Hanoi has a unique phenomenon because Motorcycle takes about 70% of the travel use (ALMEC Corporation, 2007). This high share of the motorcycle will leads to a chaotic traffic flow phenomenon because motorcycles can fill up any road space available in a short time which can cause the frequent changes of traffic flow, either expansion or compression. A statistical survey in Hanoi illustrates that more or less 50% of the surveyed households own two or more motorcycles while 86% of the households have at least one (ALMEC Corporation, 2007). Besides, this high percentage of motorcycle ownership and the phenomenon of frequent use of motorcycles may be dominant for at least one or two decades because a lack of sufficient road networks and insufficient parking spaces for 4-wheel vehicles (Shimizu et al., 2005). Undoubtedly, the use of motorcycle could bring some benefits like reducing the traffic delayed caused by public transport and maximizing the use of road space. Meanwhile, it also results in high risk of traffic accidents, easy violation of traffic regulations by motorcycle drivers as well as additional stress for other road users.

On the other hand, the congestion has always been a critical problem in Hanoi traffic situation. The traditional measures applied by the Hanoi Government to reduce the traffic congestion is exclusively relying on controlling the motorcycle ownership, but with little success. The petrol costs and the parking fee of motorcycle is cheap and it is convenient to park in many places of the city. Meanwhile, there are no specific rules of regular registration charges for motorcycles.

Unlike the predominant role of motorcycle, public transport system in Hanoi represented by a well-organized bus system run through the city only takes a very little share of travel needs, which is less than 10 percent (ALMEC Corporation, 2007). But the importance of public transport should not be ignored. Firstly, it is still the vital component in the future urban transport system of Hanoi. Secondly, it could increase the mobility in the city where there have congested situation and the private transportation becomes very slow. Thirdly, if public transport plays a positive role in people's daily transport due to a good service, it may cause a certain part of people to transform their travel modes from motorcycles to public transport. However, the current situation is that the increasing use of motorcycles and a lack of adequate public transport system in Hanoi bring about many negative effects such as congestion and environmental issue, and the necessity to change this phenomenon is pressing.

Realizing the insufficiency and the importance of public transport system in Hanoi, many transport systems are being studied and proposed by Government of Vietnam and other international donors, as shown in Figure 5. Some typical transport projects are a tram system from Hanoi central station to the west of Hanoi proposed by France, an urban railway system connecting the Hanoi city centre to south-western part of the city funded by Chinese Government. And especially a potential Bus Rapid Transit system sponsored by World Bank to serve the core city centre and the south-western suburbs of Hanoi.

This Bus Rapid Transit project in Hanoi belongs the Hanoi urban transport development project which aims to improve the mobility in targeted areas of Hanoi. Two main objectives are proposed for this project: (1) increase the use of public transport in the existing bus corridors and the new BRT corridor; (2) reduce the travel times by all travel modes in the city especially in the west and northwest parts of Hanoi. Further objective of this project is promoting the modal shift to more sustainable transport modes in the whole city. Therefore, understanding and evaluation of the proposed BRT corridor becomes an essential step before the construction of the BRT line.

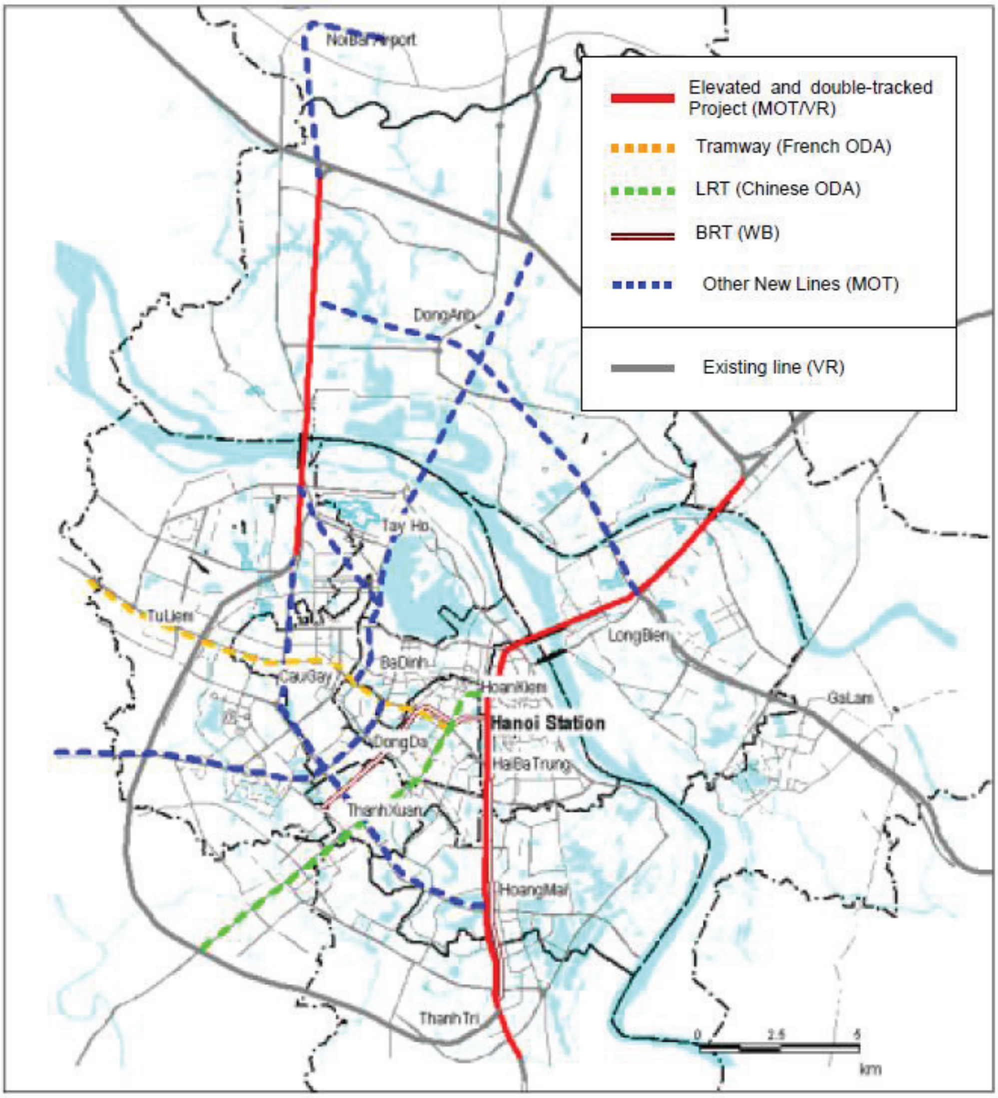

Figure 5 Transport Projects of Hanoi (Source: World Bank)

3. LITERATURE REVIEW

3.1. Concepts of BRT

BRT, short for Bus Rapid Transit, is an integrated, flexible and high performance transit system which has specialized infrastructure, design and services to improve the system quality and remove the typical causes of decay. Start from the world first BRT system in Curitiba, Brazil, an increasing number of BRT systems have emerged among the world. A typical BRT system usually have most of the following elements:

- Specialized alignment in the center of the road
- Stations with off-board fare collection
- Station platforms level with the bus floor
- Bus priority at intersections

Many benefits can be derived from the existence of the BRT system. The primary advantage of BRT is saving time for passengers comparing from the ordinary bus system because of relatively higher speeds. It also helps to avoid the typical curb-side delay, reduce the boarding and alighting delay and avoid the intersection signal delay. Apart from time-saving property, the specialized designed spacious platform will make passengers have a cosy experience when taking BRT because the size of the platform is designed according to the estimated number of passengers. This measure could effectively improve the crowded problems in congestion conditions of urban transport. Meanwhile, the travel mode changes made by BRT also contributes to an improvement of air quality, reduction of air pollution in the city especially along the BRT corridors (Nugroho et al., 2010). Generally, BRT system is a comprehensive transport system allowing higher speed, lower cost, improved capacity and better bus safety.

3.2. Evaluation of BRT

A BRT system can be measured and evaluated by a number of factors. Common metrics for evaluating a BRT system is considering its technical performance, economic performance, social-environmental performance or impacts on traffic environment. Deng and Nelson (2013) evaluated the performance and impacts of Beijing BRT line 1, the first full-featured BRT system implemented in China, considering the operational efficiency, technical performance and cost issues associated with BRT. Lessons learned from those research are improvement needs to be made on both BRT operation process and operational sustainability of BRT. Lin and Wu (2007) also summarized the application effect of BRT at Beijing south-centre corridor from management condition, service level, and social benefits, suggesting that BRT could be an effective transport system in providing high-performance services. But owing to a lack of enough data, many researchers applied indicators to focus on one or few perspectives of the BRT system and reflect the function of BRT on the urban transport.

A range of literatures has explored different indicators to evaluate the benefits a BRT system could bring to the urban people or to the entire public transport system. From the perspective of technical performance, the rail-like quality provided by BRT for the bus services could resulted in high and increasing ridership for the urban transport, especially some BRT infrastructure treatments like right of way have a significant role on this ridership benefit (Currie & Delbosc, 2011). Besides, BRT system could also contribute to redistributive effects on development pattern and property values of urban city (Jun, 2012). The related research on Seoul's BRT system applied an urban simulation model and the results indicated that the accessibility improvement made by the BRT system contributed much to the redistribution of non-residential activities but little on residential activities. While economic evaluation for a BRT system is typically represented by an ex-post cost-benefit analysis to the BRT corridors in Bogota which monetized the impacts of many transport and socio-economic indicators including travel time, travel cost, road safety factors, air quality factors as well as negative traffic factors (Hidalgo et al., 2013). From environmental aspect, Nugroho et al. (2010)evaluated the BRT system's impact in Jakarta by incorporating various cause-effect relationships among emissions, meteorology, wind, and primary pollutants. However, although the construction of BRT in Jakarta will help reduce the exhaust emissions of the whole traffic system, the BRT line also had side effects on the environmental issue like it may enhance the concentration of some negative gases near BRT line. When it comes to evaluate the possible modal shift due to the function of BRT, it was found that BRT could attract some motorists to change their travel mode choice, but most of the users still prefer private vehicles. And these kind of choices are affected by travel time, travel cost, gender, age, residential location or other socio-economic factors (SATIENNAM et al., 2013).

On the other hand, as an important indicator for measuring the benefits of transportation system, some literatures also describe the application of accessibility in evaluating BRT system. Delmelle and Casas (2012) explored the spatial accessibility landscape created by newly implemented BRT system in Cali using a transport system accessibility approach by considering both access to the BRT system itself and access to three distinct activities (hospitals, recreation and libraries) around the city. The research found that accessibility values are largely depend on the spatial distribution pattern of activities. Besides, a case study of Delhi BRT system compare the traditional accessibility indicators such as average speed of vehicles with the new proposed indicators like total time saved by all road users to evaluate the impact of BRT corridor on all types of road users. The new indicator also demonstrated the changes in competitiveness of different travel modes (Tiwari & Jain, 2012). While accessibility was also combined with affordability as a complementary method for evaluating transport policies on existing public transport system in Bogota, and give an appraisal on the impact of a new Bus Rapid Transit line. In that case, job accessibility was particularly selected as an measuring indicator (Suescun & Hernandez, 2012). A similar case in Bogota applied the accessibility by examining the ability of BRT system to land development. The results indicated that good physical access to BRT station is necessary but not sufficient conditions from land development perspectives to enjoy the benefit of BRT (RodrÍGuez & Targa, 2004). As can be concluded from the summary of related literatures above, accessibility provides new perspectives on evaluating the effectiveness and benefits of BRT system and could be a potential measure in this case for measuring the benefits of Hanoi BRT line. But the choice of the accessibility indicators and the accessibility measures should further examined.

3.3. Concepts of Accessibility

A lot of definitions explored by many researchers to define the concepts of accessibility. It can be denoted as the potential of opportunities for interaction (Hansen & Walter, 1959). Besides, it is also described as the ease with which activities may be reached from a given location using a particular transportation system (Morris et al., 1979). For the urban transport system and the land use system, it is a vital indicator because it can measure the integration and the interaction between transport and land use systems. Furthermore, evaluating transportation performance in terms of accessibility could provide a balance between the analysis of transport situation and solving transport problems. (Cervero et al., 1995). From a more specific point of view in introducing the role of accessibility in transport perspective, it can be described as for a given number of opportunities in desired destinations, the available opportunities to given origins when discounted by travel impedance between the origins and the destinations. Commonly, opportunities are represented in terms of available number of jobs and impedance are represented by distance or travel time (Niemeier, 1997).

While for this case, job accessibility could be a suitable indicator because it represents the accessibility in a more specific way. It is often composed of three parts: employers (job locations), employees (workers) and the transport system, and these three parts are not isolated from each other. The locations and distribution of jobs and residents are partly dependent by the distribution of transport system because the transport system could influence the mobility between employers and employees. While changes of resident or job distribution could inversely reflect the structure and efficiency of the transport system. However, as the interface between transport, workers and jobs, the degree of their spatial and non-spatial interactions influence a lot on job accessibility (Cheng & Bertolini, 2013). Usually, when analysing job accessibility, apart from the commonly used spatial factors like distance decay effects or competition components, non-spatial factors such as socio-economic factors are also given considerable weight.

3.4. Related Accessibility Measures

For better understanding the concepts of accessibility and selecting the suitable job accessibility measures for this research. This section will give a summary of current commonly used accessibility measures.

3.4.1. Infrastructure-based measure

Infrastructure-based accessibility measure plays an important role in current transport planning in many countries (Karst & Bert, 2004). For infrastructure, accessibility has always been an important consideration because it is always hard to balance the accessibility with sustainability especially the balance between accessibility and environmental protection (Priemus & Visser, 1995). This method makes use of travel impedance such as physical distance, travel times, congestion, travel cost, service quality or operating speed on the road network to measure the resistance between the origins and the destinations. It can be applied in the evaluation of accessibility impacts on land-use transport scenarios and related social, economic impacts (Geurs & van Eck, 2001). Besides, this measure was also utilized to set up the link between accessibility changes brought by improvements in the transportation network, and two commonly used indicators (population and purchasing power), while controlling other possible relevant variables like educational level, thus analysing the cohesion in lagging regions (Ribeiro et al., 2010).

When it comes to evaluate the effects of a transport system, travel time is always a vital indicator because it can directly reflect the efficiency of the transport system network. One typical infrastructure accessibility measure is considering a Weighted Average Travel Time measure (Gutiérrez et al., 1996). As can be seen in the Formula (1) below:

$$A_i = \frac{\sum_{j=1}^{n}(T_{ij} \times GDP_j)}{\sum_{j=1}^{n} GDP_j} \tag{1}$$

Where A_i: the accessibility of origin location i;
T_{ij}: travel time from origin location i to destination location j;
GDP_j: gross domestic product of the destination location j;
n: total number of destination locations.

Here the importance of each destination location is valued according to the economic weight (GDP) of that location. This adapted way of infrastructure-based measure relates both infrastructure efficiency (travel time) and the importance of social activities (GDP). Similarly, the economic weight GDP could be replaced by other elements such as number of jobs or purchasing power.

The data of these kind of measure is easily available from digital materials or other public sources, but the focus in the origin and destination in analysing accessibility lacks a sufficient consideration of the involvement of the land use system and the spatial distribution of opportunities. Firstly, the measure itself does not reflect the fact that the variation of infrastructure may influence the urbanization or the sprawl of land use. Secondly, the temporal variation of land use and the changes in the distribution of spatial activities could not be measured. Thirdly, social-economic factors are not taken into consideration by this measure.

3.4.2. Cumulative opportunities measure

Different from infrastructure-base measure which emphasize the role of infrastructure, cumulative opportunities measure is simple because it counts the number of opportunities within a given travel time or distance (Handy & Niemeier, 1997). Once the impedance either represented by travel time or distance is given, a certain catchment area could be defined by the infrastructure network. Here, catchment area is a user-defined area that a specific location can reach or service when calculated by fixed travel time or travel distance. Then, according to this catchment area, number of opportunities could be counted by summing up all the opportunities within this area. For example, as shown in Figure 6, for a certain healthcare centre, the number of people which could access this centre within 15 minutes by public transport could be calculated. But one disadvantage is this measure gives equal weight for all the destinations within the catchment area regardless of their distance to the origin. Besides, the influence of other possible origins outside the catchment area is ignored. Therefore the probability that a people may go to the centre could not be reflected.

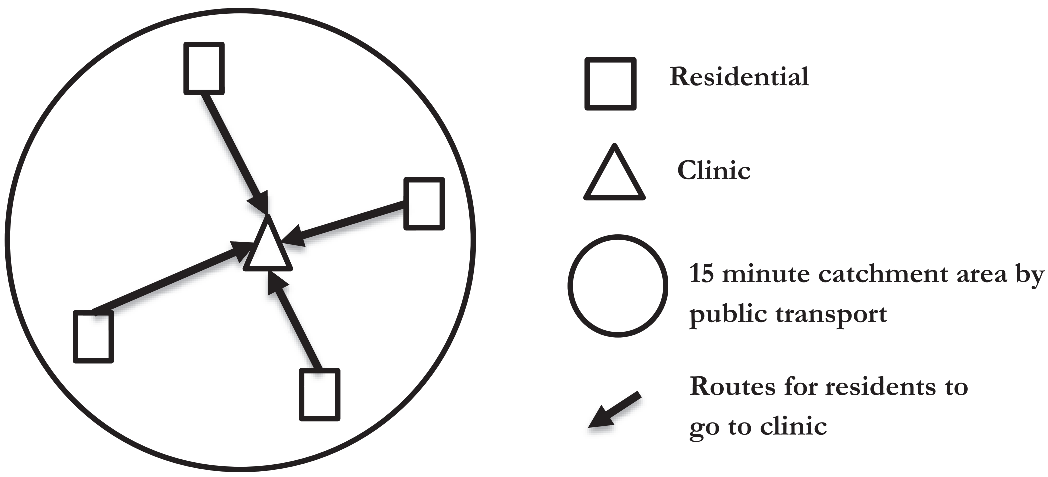

Figure 6 Example of Cumulative Measure

3.4.3. Potential measure

Unlike cumulative opportunities measure which gives all destinations the equal weight within the catchment area of an origin, potential measure distinguish all the destinations with their interaction on the origins. Rather than a simply count of opportunities within certain catchment area, this measure will give weight on the opportunities at a given location by using the characteristics of attraction (population, jobs, etc.) and discount the opportunities by impedance (Cerdá, 2009; Geertman & Ritsema Van Eck, 1995; Joseph & Bantock, 1982; Salze et al., 2011). This measure takes both the weight of attractiveness and impedance into consideration, thus give a reliable value of the potential of a given area.

The concept of potential was first proposed by STEWART (1941). After that, many researchers explored and expanded this approach into many different expressions. But the generally principle is the same which states that attractiveness of two places are positively related to the weight on both places, while inversely related to the impedance between these two places. One typical form of potential measure can be expressed as the formulas below (Salze et al., 2011):

$$A_i=\sum_{j=1}^{n} E_j \cdot f(T_{ij}) \tag{2}$$

$$f(T_{ij})=\frac{1}{{T_{ij}}^{\alpha}} \tag{3}$$

Where A_i: potential accessibility value of origin location i;
E_j: the number of opportunities in destination location j;
T_{ij}: travel time from origin location i to destination location j;
$f(T_{ij})$: distance decay effect from origin location i to destination location j;
α: the decay parameter whose range is from 0 to 1;
n: total number of destination locations.

In these formulas, E_j could be represented by number of jobs, number of population or purchasing power in destination location j. This measure particularly focuses on the interaction between origins and destinations, while the accessibility value which relates to the travel time T_{ij} could conversely reflect on the function or the efficiency of the transport system because travel time is decided by transport network.

Generally, the decay function which incorporate travel time, cost or distance can demonstrate the interaction between origin and destination. As shown in the Figure 6, all the residential locations within catchment area are not equally weighted. They weight differed from each other due to the decay effects caused by different distance. This measure distinguishes different probabilities from origin to destinations rather than giving them equal weight. But the disadvantage lies in the difficulty of defining a suitable decay function.

3.4.4. Competition-based measure

While the potential accessibility measure considers the weight on destination locations complemented by a distance decay effect to represent the final accessibility values, competition-based accessibility measure expanded the potential measure by incorporating the competition factor among the origins or the destinations (van Wee et al., 2001). For example, within a given distance (travel time) threshold the workers may have the possibilities to apply for the jobs in the nearest job location if these workers are living in the catchment area of that job location. Meanwhile these workers may also in the catchment area of other job locations, which definitely will cause the competition among these job locations. This kind of competition also happens in the demand side for the workers to compete for the limited jobs. A further explanation of competition-based measure can be concluded from the figure below. As shown in Figure 7, residential location A is in the catchment areas of both clinic B and clinic C by 15 minutes public transport, thus it will face the competition from both clinics.

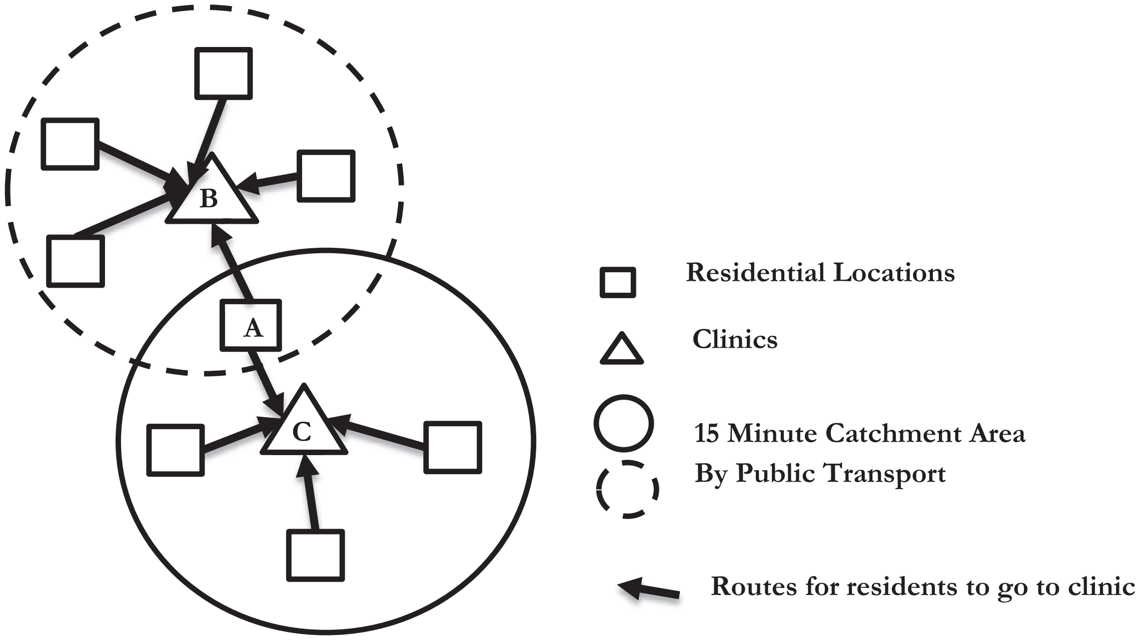

Figure 7 Example of Competition-based accessibility measure

One typical way of measuring accessibility is called Floating Catchment Area (FCA) method. This measure assume a certain threshold such as travel time or travel distance as the impedance and according to this impedance, a catchment area base on the supply side are created. Then by accumulating all the opportunities in the catchment area, a supply to demand ratio could be calculated (Luo, 2004). But this measure gives the assumption that the demand side is fully available for the supply side and the competition among the supply side is not considered. Therefore, a Two Step Floating Catchment Area method is developed which repeats the process of "floating catchment" twice (Wang & Luo, 2005). This method incorporate the competition among the supply sides, and indicates the potential probabilities that the demand (e.g. people) would go for each supply (e.g. clinics). But it also lacks of a consideration among competition on demand sides.

For analyse job accessibilities, the competition not only happens in the supply side (job locations), but also happens in the demand side (workers). In order to show the interaction between supply and demand sides, Cheng (2013) developed a competition-based model which considers job diversities, decay function, competition among supply and demand sides to analyse the accessibility of workers in Amsterdam. This method can be seen from the formulas below:

$$D_j = \frac{\sum_l Q_{lj} \times \ln(Q_{lj})}{\ln(n)}, Q_{lj} = \frac{E_{lj}}{E_j} \tag{4}$$

$$f(T_{kj}) = e^{-\beta \times T_{kj}} \tag{5}$$

$$P_{jk} = \frac{{E_j}^{D_j} \times f(T_{kj})}{\sum_s {E_s}^{D_s} \times f(T_{ks})} \tag{6}$$

$$O_i = \sum_j \frac{E_j \times P_{ji} \times W_i \times f(T_{ij})}{\sum_k P_{jk} \times W_k \times f(T_{kj})} \tag{7}$$

Where D_j: the job diversity in job location j;

E_{lj}: the number of type l jobs in job location j;

E_j: the total number of all jobs in job location j;

n: the number of job types in job location j;

$f(T_{kj})$: distance decay function between residential location k and job location j;

T_{kj}: travel time from residential location k to job location j;
β: decay parameter whose range is from 0 to 1;
P_{jk}: a probability value representing the competition factor among job locations;
O_i: Job opportunity in residential location i

Different from potential accessibility measure, after incorporating the competition factors among both supply and demand side, the final job accessibility in each residential location was calculated in a more exact way. For example, suppose a job location j has 300 jobs and when calculated by potential accessibility measure, the final results may be 200 jobs are potentially available for residential location i while 150 jobs are potentially available for residential location k. But it can be found from the results that total available job opportunities for these two residential locations is 350, which is greater than the actual number of jobs 300 in job location j. This is because potential measure does not account for competition factors in the accessibility calculation, thus cause a double count in job numbers. Under same conditions, when using competition-based accessibility measure to calculate job accessibilities, the final job opportunities in residential location i may be 180 while for residential location k this figure is 120. This means that the way competition-based measure is calculated will not cause double count of job accessibility because it takes the roles of competition. This kind of competition-based view can better address the issue of the spatial relationship between job demand and supply in the network (Cheng & Bertolini, 2013).

3.4.5. Selection of Accessibility Measures

In the whole, many accessibility measures have been used for measuring job accessibility and some of the measures are already played important roles in relating job accessibility with transport networks. The main objectives of these research is to evaluate the benefits of BRT from accessibility perspective and particularly choose job accessibility as an important indicator. But what kind of job accessibility measure could be utilized in this case? The choice of the accessibility measure should basically rely on two aspects. On the one hand, it should reflect the benefits of BRT line in Hanoi directly by the indicator of job accessibility. This kind of reflection could be the comparison between the changes of job accessibility in Hanoi before and after the BRT line is constructed. On the other hand, the accessibility measure itself should be suitable for analysing the case of Hanoi based on current available data and could easily be interpreted.

Based on these two principles, three types of job accessibility measures are chosen to be applied in this research for analysing job accessibilities thus evaluate the benefits of BRT in Hanoi. Firstly, travel time is a very crucial factor because it measures the efficiency of a transport system. However, when analysing job accessibility, travel time should be integrated with the role of jobs. Therefore, the Weighted Average Travel Time measure (described in Section 3.4.1) is adopted in this research to links the travel time and the weight of jobs, thus evaluating the benefits of BRT from travel time point of view. Secondly, the traditional potential measure is a commonly used accessibility measure in transport analysis because the results of this measure demonstrates how transport system affects the attractiveness of certain locations. The attractiveness of certain locations are discounted by distance decay effect, and different locations have different decay effect because the function that a transport system acts on them is different. Therefore, this research will also utilize potential accessibility measure to see the benefits of BRT line. Thirdly, Cheng's competition-based accessibility measure is a comprehensive accessibility measure because it contains a lot factors of job diversity, distance decay effects and competition components (Cheng et al., 2013). This measure was also applied in examining job accessibility conditions of Ahmedabad to measure the effect of infrastructure projects of Ahmedabad (Zhen, 2013). Besides, the way of calculating accessibility in Cheng's measure is different from potential measures due to the incorporation of competition component. Therefore, this research will also use Cheng's competition-based accessibility measure to explore the benefits of BRT line.

4. METHODOLOGY

4.1. General Description of Data Preparation

For analysing the job accessibility in the study area of urban Hanoi, three parts of data are required in the whole research process.

- Firstly, the spatial distribution of residential locations and the job locations in the study area needs to be defined, which is the basis for accessibility analysis. The population number in each residential location should be calculated or estimated. Besides, in each job location, focus is on the number of job types in that place and the corresponding job numbers for each job type.
- Secondly, transport system of Hanoi could be represented by constructing a Multi-modal Road Network. This Multi-modal Road Network is a road network in ArcGIS representing the basic transport structure of urban Hanoi. Road lines, bus lines, BRT lines, bus stops, BRT stops and other basic infrastructure component. It could be used to represent different travel modes among walking, motorcycle, bus and BRT. Each travel mode could be utilized specifically or combined with other modes in simulating the travel behaviors of workers in Hanoi. From the Multi-modal Road Network, the travel time for a worker from a specific residential location to a specific job location by travel modes (walking, motorcycle, bus or BRT) could be calculated.
- Thirdly, based on the spatial distribution of job locations, residential locations and the travel time from each residential location to each job location, the job accessibility of each residential location could be calculated. There are three job accessibility measures applied in this research: (1) Weighted Average Travel Time. (2) Potential Accessibility Measure. (3) Competition-based Accessibility Measure.

The original data which are available is displayed in the Table 2 below.

Table 2 Data Description

Data Name	Type	Explanation	Year
Land use	Shape file	Polygon data describes the distribution of land use types in urban Hanoi includes residential, government office, business, school, hospital, etc.	2010
Population per ward	Shape file	Polygon data shows the distribution of communes and wards in urban Hanoi and the population of each commune or ward is given.	
Job data	Excel file	A governmental official employment data describes the number of jobs in different sectors and subsectors in total Hanoi. The number of jobs in the study area is about 50% of the total.	
Road network	Shape file	A multiline feature demonstrates the basic road network in urban Hanoi. The road category includes Expressway, primary road, secondary road, streets, lanes, etc.	
Bus network	Shape file	A multiline feature includes bus lines and bus stops in urban Hanoi.	
BRT line	Shape file	Digitized	

4.2. Data Preparation of Job Locations and Residential Locations

1) Data Processing Justification

In the job accessibility modelling process, the requirement for residential locations and job locations is using the point layers (a data type in ArcGIS) to represent the spatial distribution of these locations. Besides, the attribute of these locations such as number of jobs, job types or number of population should also be included in the attribute of these point layers. These point layers could be utilized in the Origin-Destination cost Matrix (A function in ArcGIS based on Multi-modal Road Network) to find the possible shortest routes and shortest travel time from each origins to each destinations.

There are no primary data about the spatial distribution of job locations and residential locations in the study area. The available data about jobs is a governmental official employment data containing the number of jobs in different job types in Hanoi, but lack of describing how these jobs are distributed spatially in the study area. The available data about the possible spatial distribution of jobs is the land use data categorized by different types of land use in urban Hanoi. Therefore it is necessary to find a way to assign the jobs spatially to the study area based on the land use data.

On the other hand, the available data about population is a population data contains the total number of population in each community of urban Hanoi, but the exact distribution of population in each community is not defined. Therefore, the residential areas in the land use data could be utilized for distributing population in the study area.

2) Reclassification of job types

The flowchart of how jobs were assigned in the study area is shown in the Figure 8. The original governmental official employment data has four major types: Industry, Government Office, Business Enterprise and Social Services. In this research, the original job data was reclassified into 7 job types which could better represent job diversity factor. Job diversity is a job attribute describes the total types of jobs in a certain area, it is an important component in the competition-based accessibility measure that will be applied in this research (Section 3.4.4). The seven reclassified job types are: (1) Industry, (2) Government office, (3) Business, (4) Health, (5) Education, (6) Transport, (7) Other social service. There are total number of 2010794 jobs in the study area, the details of the reclassification rules are displayed in Table 3 below.

3) Reclassification of Land Use

After jobs are reclassified into seven types, the possible lands for job locations in the land use data should be selected out. The reason for this kind of selection is that owing to a lack of data about job spatial locations in urban Hanoi, the possible way to assume the spatial location of jobs is by utilizing the land use data. But the land use data does not contain any employment information, therefore theses selected land use data should be reclassified into the same seven types to match the job types that have been reclassified. The detail classification rules of land use are demonstrated in Table 4 below. The classification rule is based on the property of each land use.

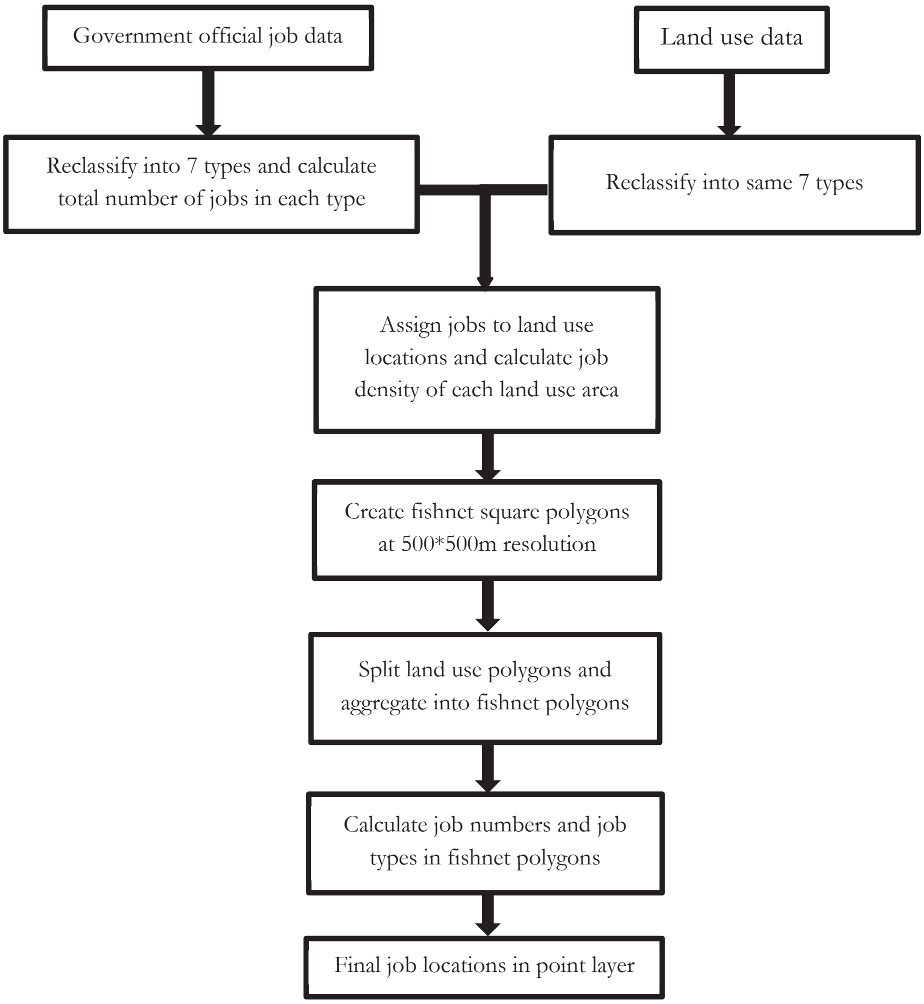

Figure 8 Flowchart of Distributing Job Locations

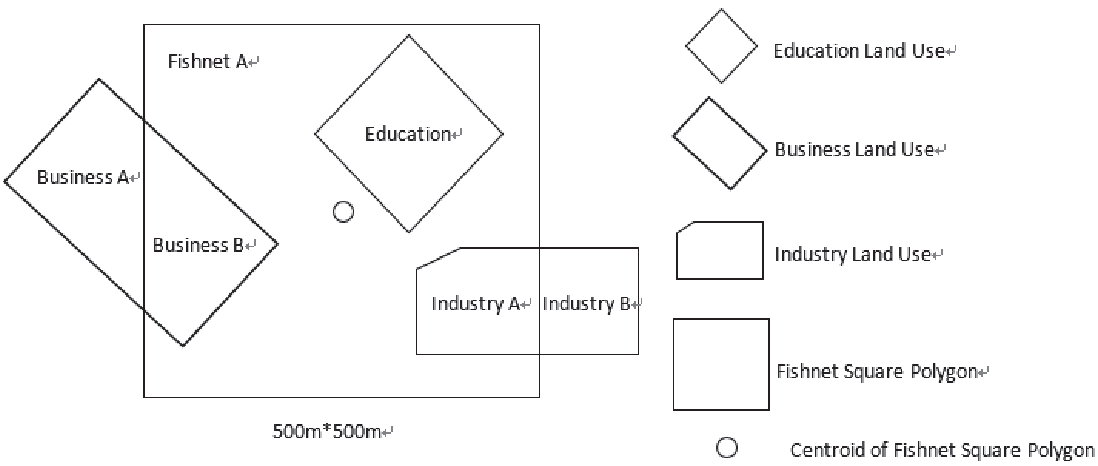

Figure 9 Example of Aggregating Jobs into Fishnet Square Polygons

4) Distribute jobs to land use locations

First of all, for each job type that has been reclassified, there is a figure represent the total number of jobs in that type. Then select out the corresponding land use areas of each job type and sum up the whole land use areas with which the total land use area of each job type could be obtained. After that the job density (number of jobs per square meter) of each job type could be calculated with the Formula (8) below:

$$Job_{density(people/m^2)} = \frac{Total\ number\ of\ jobs\ in\ that\ type(people)}{Total\ land\ use\ areas\ of\ that\ type(m^2)} \tag{8}$$

Finally, after the calculation each land use location could be assigned a job type and a corresponding job density. For example in Equation 8, the total number of jobs in "Industry" type is 613091 and the total area of land use which belongs to "Industry" is 15615741m^2, thus the job density of "Industry" type is 613091/15615741=0.03926 people/m^2.

i. Owing to the fact that land use shape file are represented by polygons and this kind of shape could not be utilized in the Origin-Destination analysis (a function in ArcGIS which will be introduced in Section 4.3) of accessibility modelling process, a data transformation is necessary to transform the land use polygon data into point feature class. The total number of land use polygons are 16451, but these locations need to be aggregated according to a suitable resolution. On the one hand it could reduce the burden of calculation, on the other hand the job diversity factors could be represented in the data. Therefore, one possible solution is to use squares at a suitable resolution to aggregate the original land use areas and use the centroid of these squares to represent the spatial location of jobs.

ii. For defining the cell resolution in job locations, it should neither too small so that the job diversity factor could be represented nor too large so that the aggregation mistakes and errors could be reduced. Therefore, fishnet square polygons was created at the resolution of 500*500 meters(Cheng & Bertolini, 2013) to aggregate the jobs locations.

iii. After the fishnet square polygons were created, a union tool in ArcGIS (a data processing function) was performed to cut and split the selected land use polygons into smaller polygons base on the boundary of fishnet squares. This process is to split the large land use polygons into smaller polygons so that the jobs of these smaller polygons could be aggregated into the fishnet square polygons it was covered.

iv. After the splitting process, the smaller land use polygons covered by each fishnet square polygons represented a specific job type and its spatial location. Then for each smaller land use polygons, use the job density that has been calculated by Equation (8) to multiply its shape area to get the total number of jobs in that polygon. After that, for each fishnet square polygon, sum up the total type of jobs and total number of jobs within the square polygon. Eventually, the centroid of each fishnet square polygon was applied to represent the newly created job locations and each location contains the data of "job diversity" (total type of jobs) and the number of jobs for each type.

As can be seen in the Figure 9, there are three land use polygons covered or partially covered by Fishnet A: Education, Business and Industry. If we use the boundary of fishnet square A to cut the land use areas, the job types within fishnet A are three, and the total number of jobs in fishnet A are calculated by Formula 9 below:

$$\begin{aligned} Jobs_{Fishnet\ A} &= Jobs_{Education} + Jobs_{Business} + Jobs_{Industry} \\ &= Density_{Education} \times Area_{Education} + Density_{Business} \times Area_{Business\ B} + \\ &\quad Density_{Industry} \times Area_{Industry\ A} \end{aligned} \tag{9}$$

After the aggregation, there are total 1037 job locations represented by point layers at a resolution of 500*500. And the final job distribution after the data process in the study area is given in Figure 10 below.

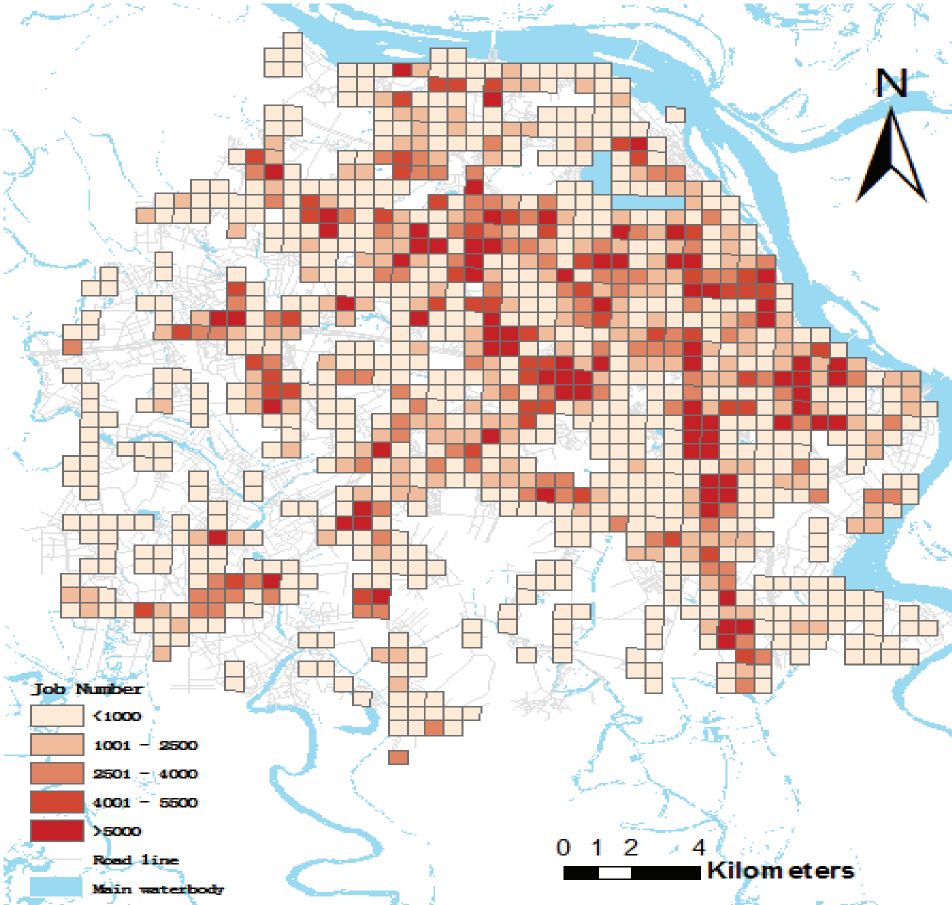

Figure 10 Final Job Location Distribution in the Study Area

5) Define residential locations

i. For the residential areas, the population data for each community is available in the study area, but the exact spatial location of the population is not defined. Therefore the land use data could applied to define the spatial location of residential areas.

ii. Select out all the land use areas where the population could be assigned to these areas. They are: (1) New Urban Area; (2) Urban Area; (3) Urban Residential; (4) Village; (5) Village Hall; (6) Village-Urban. Furthermore, these areas was classified into two parts where (1), (2), (3) are combined as "urban areas" and (4), (5), (6) are combined as "rural areas". According to the land use property, the population is possible to distribute in these selected 'residential areas'.

iii. A spatial join function in ArcGIS was made to combine the community polygons with the selected 'residential areas'. After the spatial join function, some community polygons are covered by pure "urban areas", some community polygons are covered by pure "rural areas" while some community polygons are covered by both "urban areas" and "rural areas". For the communities purely covered by either "urban areas" or "rural areas", just assign the population in that community into these areas. But for the communities which contained both "urban areas" and "rural areas", an assumption is required to estimate the population percentage of "urban areas" and "rural areas" in those communities. There are no strict statistical data can be applied to assume the population percentage, therefore one possible solution here is to use the ratio between total population of all communities covered by pure "urban areas" and the total population of all communities covered by pure "rural areas". The result of this ratio is 8 to 2, which means in the communities covered by both "urban areas" and "rural areas", the population of "urban areas" occupies 80 percent while the population of "rural areas" occupies 20 percent. This population proportion can be utilized to assign the populations in the communities covered by both "urban areas" and "rural areas".

Then in each community, sum up shape areas of all the "urban areas" or "rural areas" and use the follow formulas to calculate the population density in each residential area:

- For the communities purely covered by "urban areas" or "rural areas":

$$Population_{density(people/m^2)} = \frac{Total\ number\ of\ population\ in\ that\ community(people)}{Total\ shape\ areas\ of\ urban\ (rural)\ areas(m^2)} \quad (10)$$

- For the communities covered by both "urban areas" and "village areas":

$$Population_{urban} = Population_{Community} \times 80\% \quad (11)$$

$$Population_{rural} = Population_{Community} \times 20\% \quad (12)$$

$$Population_{density(people/m^2)} = \frac{Total\ number\ of\ population\ in\ urban\ (rural)\ areas(people)}{Total\ shape\ areas\ of\ urban\ (rural)\ areas(m^2)} \quad (13)$$

v. After populations are assigned into those "urban areas" or "rural areas", the shape of these areas are still too large so that if we use the centroid of these areas to represent the total areas, there will be huge errors in the calculating process. Therefore fishnet square polygons at the resolution of 500*500 was created to disaggregate these "urban areas" and "rural areas". After that a union function in ArcGIS was applied to split the residential locations into smaller polygons base on the boundary of fishnet squares. This process is to split the large land use polygons into smaller polygons so that the population of these smaller polygons could be assigned to the fishnet square polygons it was covered.

vi. The next step is using the population density of each smaller polygon multiply the shape area of each smaller polygon to get the total population of each smaller polygon.

iv. Finally, for each fishnet square polygon, sum up the total population of all the smaller polygons in that square and use the centroid of square to represent the new residential locations. The final number of residential locations after disaggregation is 1195. And the final distributions of residential locations are shown in Figure 11 below.

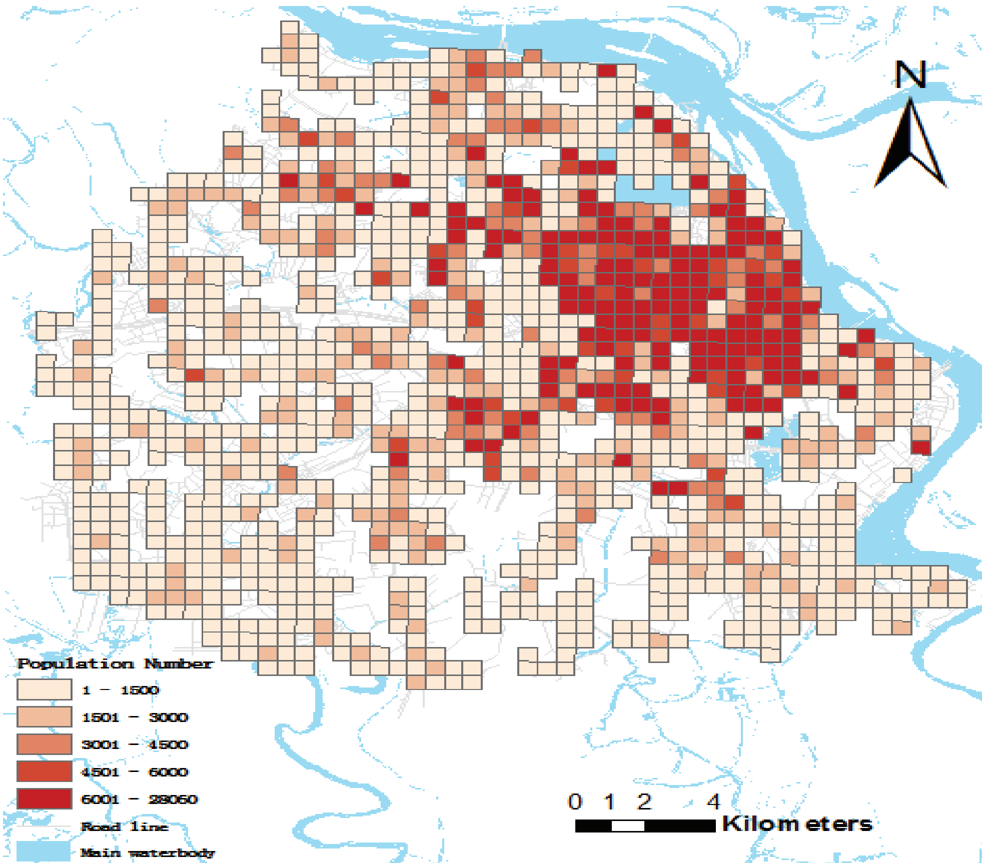

Figure 11 Final Residential Location Distribution in the Study Area

Table 3 Reclassification of Job Sectors

No	Reclassified job type	Original job type	Total number of jobs (people)
1	Industry	Mining	613091
		Manufacturing industry	
		Electricity, gas, steam	
2	Government Office	Communist party, socio-political organization	248655
		Administration and support services	
		Science and technology	
		Administration in education field	
		Administration in Healthcare field	
3	Business	Agriculture-Forestry-Fishery	694466
		Construction	
		Whole sales and retail trade, repair of vehicles and motorcycles	
		Accommodation and food services (Hotel, restaurant)	
		Information and communication	
		Financial, banking and insurance	
		Real estate	
		Tourist services	
		Property business and consulting service	
		Water supply, sewerage, waste management	
		Other business services	
4	Health	Doctor	14115
		Assistant to doctor	
		Nurse	
		Pharmacists	
5	Education	Lecturer in university and college	73310
		Teacher in technical vocational college	
		Teacher in kindergarten	
		Teacher in Primary school	
		Teacher in Secondary school	
		Teacher in high school	
6	Transport	Transportation and storage	56082
7	Other Social Service	Personal and public services	19394
		Cultural and sporting services	
		art, entertainment and recreation	

Table 4 Reclassification of Land Use

No	Reclassified land use type	Original land use type
1	Industry	Heavy Industry
		Industry
		light industry
2	Government Office	Administrative Office
		Community Hall
3	Business	Business and production enterprise
		Hotel
		Market
		Post Centre
		supermarket
4	Health	Health Clinic
		Hospital
5	Education	College
		Education Centre
		Research Institute
		School
		School-high
		School-infant
		School-Primary
		school-primary and secondary
		school-secondary
		school-secondary and high
		university
6	Transport	City Bus Station
		Gasoline station
		Inland Port
		Railway Station
7	Other Social Service	Church
		Cinema
		Exhibition Area
		Historical and Tourist area
		Library
		Museum
		Park
		sport centre
		stadium
		temple
		Tourist area

4.3. Transport Data

1) General Description of Road Networks

The transport system of the Hanoi city which will be applied in this research is mainly composed of three parts, as shown in Figure 12:

- A road line representing the basic roads in Hanoi which has eight categories of roads: (1) District road; (2) Expressway; (3) Local main street; (4) National road; (5) Primary road; (6) Province road; (7) Secondary road; (8) Small road. This line is for motorcycle and pedestrian walking.
- A bus line representing the bus system in Hanoi.
- A BRT line representing the proposed constructed BRT line through the urban Hanoi.

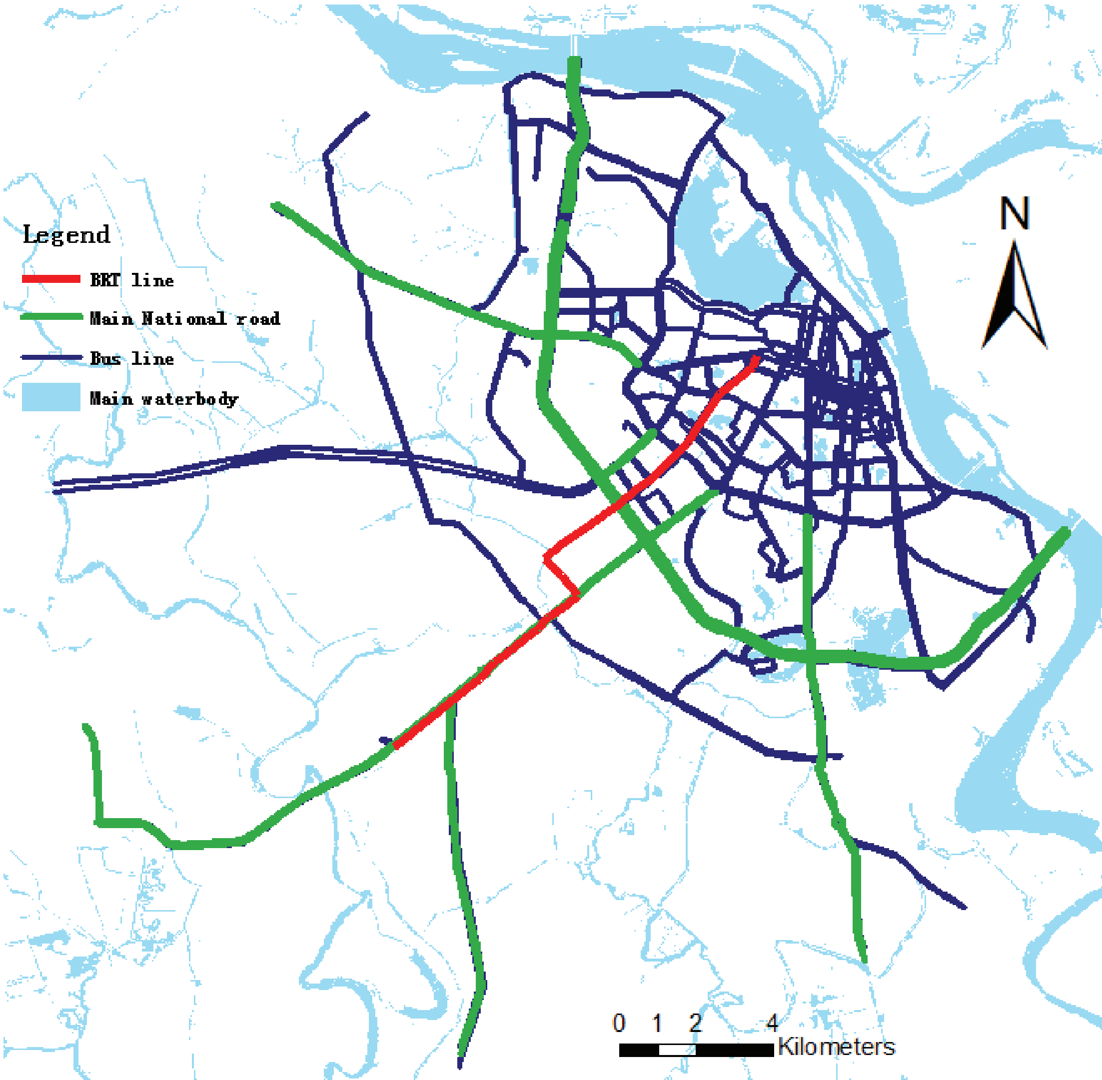

Figure 12 Road Networks and Public Transport System in Urban Hanoi

2) Assumptions of the Travel Speed and Travel Time

The assumptions of travel speed by different travel modes are given in the Table 5 below.

Table 5 Properties of the Road Network

Mode	Road Attribute	Speed (km/h)	Access	Egress
Motorcycle	Expressway	45	N/A	N/A
	National road	40		
	Primary road, Province road	35		
	District road, Local main street, Secondary road	30		
	Small road	25		
Bus	City Centre	15	10 min	20 seconds
	Urban Fringe	20		
	Out of City Centre	25		
BRT	N/A	25	3 min	20 seconds
Walking	N/A	3.5	N/A	N/A

The average speed of walking, bus, BRT and the corresponding access and egress time are obtained from Hanoi Master Plan in 2007 (ALMEC Corporation, 2007) and the Hanoi Urban Transport Development Project in World Bank Project (World Bank, 2007). The average speed of motorcycle is obtained and adapted from Ha (2011). The speeds of all transport modes are assumed to keep the average speeds as demonstrated in the table during the day. The travel time of each road segment is estimated by ArcGIS software using the lengths and the travel speed on each road. The Access means the time people use to wait for the public transport. The Egress means the time people use to leave that public transport.

3) Constructing of Road Networks

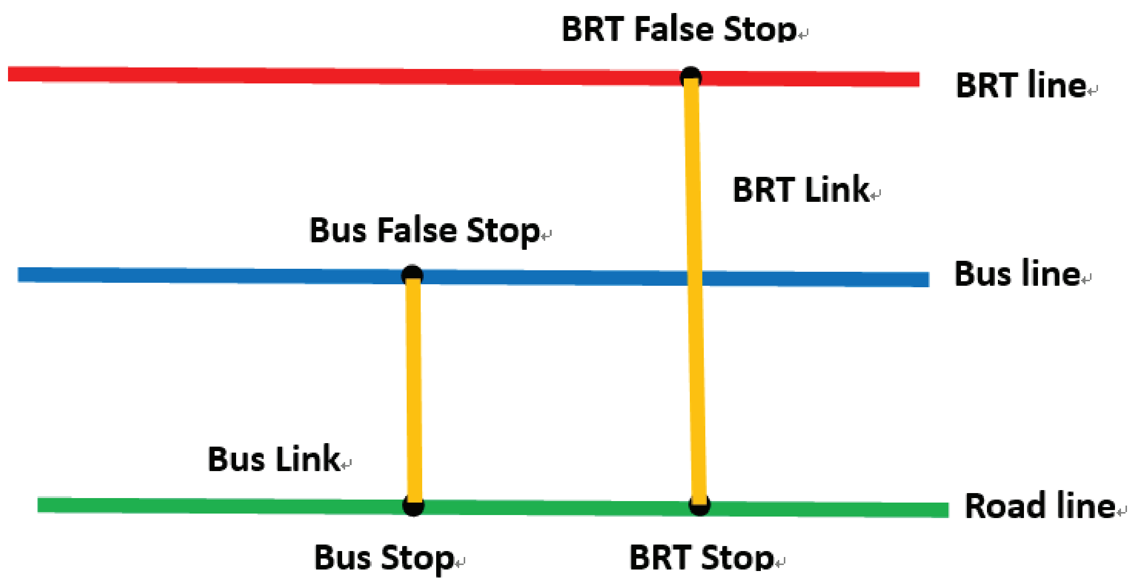

Figure 13 Brief Graph of Multi-modal Road Networks

Shown above in Figure 13 is a simple graph describing the principle of Multi-modal Road Networks in this research. There are three parts composed to formulate the road networks. The first part is the road line which is used for motorcycle running and pedestrian walking. In the road line there are bus stops and BRT stops attach to the centre of the line. Bus line is set in the second part where bus false stops are attached to it. False stops are not real exist stops. They are points to be assumed to attach to the bus lines or BRT lines in the road networks. Each false stop matches a real exist stop in the road line. And this match can be represented as line links between the false stop and its matching stop. Those line links in the road networks could be utilized for setting the access time and egress time. This also makes the restriction in the network that people can only get access to bus line from bus stops in the road line. The same principle goes for BRT line. If a worker wants to start from his home (Origin) to his working place (Destination), the ArcGIS software will automatically compare all the alternative routes of all possible combination of travel modes such as Walking; Walking combine Bus; Walking combine BRT and then select out the route which takes the shortest time. This kind of processing in ArcGIS software is called Origin-Destination Cost Matrix with which the outputs are the travel time and the travel length from each Origin to each Destination. In this research, the Origins are the residential locations and the Destinations are the job locations.

4) Transport Scenarios

Hanoi is a unique city where motorcycle occupies the majority of the travel share. But after the BRT is constructed in Hanoi city, a certain amount of people may change their travel modes from motorcycle to public transport owing to the benefits from the newly constructed BRT line. From the accessibility point of view, it is difficult to estimate the possible percentage of travel mode changes. Therefore, four transport scenarios are constructed by different combination of travel modes and the comparisons could be made from the job accessibility difference.

Current Situation: Before the constructing of BRT line.

- Scenario 1: Motorcycle
  Before the constructing of BRT line, motorcycle is the predominant transport mode in Hanoi. Therefore the first scenario is assuming that all people use motorcycles to the work place. This scenario will analyze the job accessibility distribution caused by the use of motorcycle in Hanoi to see the general influence of motorcycle.
- Scenario 2: Walking + Bus
  Besides motorcycle, in current situation public transport (bus) is also a travel mode that people in Hanoi often use to go to work. The second scenario is assuming all people will have a combination use of walking and buses to work. This scenario assumes workers will estimate the travel time from living locations to job locations and then decide whether walking directly to job locations or take a bus there depend on the shortest travel time. Therefore this scenario intends to simulate the job accessibility distribution caused by the travel mode of walking and buses.

Future Situation: After BRT line is constructed.

- Scenario 3: Walking + Bus + BRT
  After BRT line is constructed, the potential influence will be the modal shift from motorcycle to public transport because BRT line provides more travel mode choices from living locations to job locations for the people in urban Hanoi. The third scenario is after the constructing of BRT line, assuming all people will have a combination use of walking, bus and BRT to work place. In this scenario, people will estimate the travel time for all possible travel modes among walking, bus and BRT and choose the one or the combination of travel modes which takes the shortest time.

4.4. Accessibility Model

For analysing the job accessibility levels in urban Hanoi, three accessibility measures was applied in this research. The first measure is the Weighted Average Travel Time, the second measure is the traditional Potential Accessibility Measure and the third measure is the Competition-based Accessibility Measure.

4.4.1. Measure 1: Weighted Average Travel Time

This measure considers the potential benefits of BRT line from travel time point of view. Two elements are taken into consideration, thus

1) Travel times from each Origin (residential location) to Destination (job location) through the road networks of Hanoi by minimal travel times are calculated.
2) The importance of the Destinations are valued and weighted based on the number of jobs in each Destination.

Therefore, this measure calculates a weighted average of travel time with respect to the job numbers in each Destination. The methods of calculating the weighted average travel time are adapted from a previous accessibility model which was utilized in analysing the European high-speed train network (Gutiérrez et al., 1996). The accessibility value can be calculated based on the formulas below:

$$A_i = \frac{\sum_{j=1}^{n}(T_{ij} \times E_j)}{\sum_{j=1}^{n} E_j} \tag{14}$$

Where A_i: the accessibility of residential location i;
T_{ij}: travel time from residential location i to job location j (in minutes) which can be calculated by the Origin-Destination cost matrix function from Multi-modal Road Networks of urban Hanoi;
E_j: number of jobs in job location j;
n: the total number of destination locations.

4.4.2. Measure 2: Potential Accessibility Measure

The traditional potential accessibility measure is based on the basic assumption that there are spatial interaction between each residential location and job location. This kind of interaction will cause a discount effect that not all the jobs in each job location is available for each residential location. They will be discounted by a distance decay effect. The decay parameter is a value of this effect which ranges from 0 to 1, standing for the proportion of available jobs to the total jobs in each job location. The formulas below are applied in this research for calculating the potential accessibility in urban Hanoi (Salze et al., 2011):

$$A_i = \sum_{j=1}^{n} \frac{E_j}{T_{ij}^{\alpha}} \tag{15}$$

Where A_i: potential accessibility value of residential location i;
E_j: the number of jobs in job location j;
T_{ij}: travel time from residential location i to job location j (in minutes) which can be calculated by the Origin-Destination cost matrix function from Multi-modal Road Networks of urban Hanoi;
α: the decay parameter whose range is from 0 to 1 which will be described in Section 4.4.3;
n: total number of job locations.

This potential measure describes a spatial effect that job accessibility of a residential location has a positive proportion to the weights (number of jobs) on the target job location and is inversely relates to the travel time between two locations.

4.4.3. Measure 3: Competition-base Accessibility Measure

1) General Description of Accessibility Model

The Competition-based Accessibility Measure applied in this research is adapted from Cheng's Accessibility Model (Cheng et al., 2013). The job accessibility is represented by job opportunity which could be obtained from the formulas below.

$$D_j = \frac{\sum_l Q_{lj} \times \ln(Q_{lj})}{\ln(n)}, Q_{lj} = \frac{E_{lj}}{E_j} \tag{16}$$

$$f(T_{kj}) = \frac{1}{T_{kj}{}^{\alpha}} \tag{17}$$

$$P_{jk} = \frac{E_j{}^{D_j} \times f(T_{kj})}{\sum_s E_s{}^{D_s} \times f(T_{ks})} \tag{18}$$

$$O_i = \sum_j \frac{E_j \times P_{ji} \times W_i \times f(T_{ij})}{\sum_k P_{jk} \times W_k \times f(T_{kj})} \tag{19}$$

Where D_j: the job diversity in job location j;

E_{lj}: the number of type l jobs in job location j;

E_j: the total number of all jobs in job location j;

n: the number of job types in job location j;

$f(T_{kj})$: distance decay function between residential location k and job location j;

T_{kj}: travel time from residential location k to job location j (in minutes) which can be calculated by the Origin-Destination cost matrix function from Multi-modal Road Networks of urban Hanoi;

α: decay parameter whose range is from 0 to 1;

P_{jk}: a probability value represent the competition factor among job locations;

O_i: Job opportunity in residential location i;

W_i: the number of workers in residential location i.

Generally, D_j is the job diversity in job location j. This value ranges from 0 to 1 where 0 represents that there is only one type of job in the job location j and 1 represents that in job location j job numbers of all types of jobs are equal. Equation (18) demonstrates the competition among the supply side, that is to say the competition for employees in residential location k among all the job location that are available for location k. In particular, it illustrates the probability that employees in residential location k would apply for the jobs in job location j. Finally, if the competition among the demand side is considered, there is the Equation (19) represented as job opportunity O in residential location i which incorporates job diversity, distance decay, competition among supply side and the competition among demand side. This is the final job opportunity value represented in the Competition-based Accessibility Measure.

2) Decay Function

Distance decay is an effect representing the mutual interaction between two locations. Generally based on the principle of Newton's Gravity Law, with the increase of distance between two locations, the mutual interaction or attractiveness of two locations will decrease. When this effect is reflected on the traveling, the increasing of distance means the increasing of travel time, therefore travel time between two locations become an important indicator in the distance decay function.

According to the equation (15) in the accessibility model, T_{kj} is the travel time between residential location k and job location j which could be estimated based on the Multi-modal Road Networks. The only uncertainty parameter in this equation is the α value.

One common methods to define the α value is by analysing the trip survey samples which tells about the relations between travel time, travel distance and travel frequency in a city. But due to the lack of travel survey data, the defining of the α value can be concluded from the previous research of the Hanoi case or estimated by the data available. Ha (2011) estimated 0.5 as the α value according to the average travel time for people to work place in Hanoi in 2007 (ALMEC Corporation, 2007). Due to a lack of supportive and persuasive data to estimate a suitable α value for the distance decay function, therefore this research will apply 0.5 as the α value which has been used before.

5. ACCESSIBILITY RESULTS AND ANALYSIS

This chapter mainly contains two parts of accessibility analysis. Firstly, a comprehensive job accessibility analysis will be made on the whole urban Hanoi using three accessibility measures: Weighted Average Travel Time; Traditional Potential Accessibility Measure; Competition-based Accessibility Measure. Secondly, further study will be made on a service area along the BRT corridor also from accessibility perspective. Different transport scenarios will be applied in both parts for comparing and evaluating job accessibility differences. Three basic scenarios are:

- Scenario 1: Motorcycle
  Assuming that all people use motorcycles to the work place.
- Scenario 2: Walking + Bus
  Assuming all people will have a combination use of walking and buses to work.
- Scenario 3: Walking + Bus + BRT
  Assuming all people will have a combination use of walking, bus and BRT to work place.

5.1. Accessibility Analysis for the Urban Hanoi

5.1.1. Measure 1: Weighted Average Travel Time

As mentioned before, this measure calculates the average travel time from each residential location (origin) to all the job locations (destinations) and each job location is weighted by the number of jobs of that location. The travel time from each origin to destination is calculated by an Origin-Destination Cost Matrix function in ArcGIS 10.2 Network Analyst extension.

In the current situation, Figure 14 demonstrates the weighted average travel time distribution by motorcycles (Scenario 1) in urban Hanoi. The value of weighted average travel time of all origins ranges from 15 minutes to 46 minutes with an average value of 26 minutes, as displayed in Table 6, this meets the convenience and rapidity characteristics of motorcycles. Notice should be given that the central parts of urban Hanoi have the lowest value of weighted average travel time while from the centre expands to the outer boundaries which covers suburban areas and rural areas this time value increased gradually. This indicates that people living in middle parts of urban Hanoi have a relatively lower average travel time to all job locations in the city compared with people living in outer boundary of the city. This may be due to that road lines for motorcycle travel are more concentrated in the city centre areas which covers from middle part to North-East part of urban Hanoi. Meanwhile, most of expressways, national roads and primary roads are all passing through these areas, thus increase the mobility and accessibility of these areas.

On the other hand, the weighted average travel time of two public transport scenarios (Scenario 2 Walking + Bus, Scenario 3 Walking + Bus + BRT) have the similar distribution as motorcycle (Figure 15, Figure 16) which the central parts close to the city centre has the lowest values and with farther away from the central, the time values have a general tendency to increase. From Table 6, it can be concluded that the travel time of these two scenarios are both ranging from 45 minutes to 208 minutes which the Scenario 2 (Walking & Bus) has a mean value of 78.2 minutes while the Scenario 3 (Walking & Bus & BRT) has a mean value of 78.0 minutes. These mean values are roughly the three times by the mean value of motorcycle scenario, indicating that the motorcycle still has absolute speed advantages over public transport whether BRT exist or not. The weighted travel time of these two scenarios are apparently lower than that of motorcycle, thus the comparison between the weighted average travel time of motorcycles (Scenario 1) and the public transport (Scenario 2 & 3) is not very meaningful to reflect the influence brought by BRT line. Therefore the further step is to just compare the weighted average travel time value between Scenario 2 (Walking & Bus) and Scenario 3 (Walking & Bus & BRT). The comparison of these two scenarios are shown in the Figure 17, which compares the weighted average travel time value of every residential location in urban Hanoi by using a travel time ratio of Scenario 3 to Scenario 2. From the comparison results, it seems that after BRT is constructed, all residential locations will reduced their weighted average travel time, but this kind of reduction is very slight with an average of 0.3% in the whole area. But 6 out of 1195 residential locations along the BRT line gets a slight more benefits from travel time saving (10%-20%). This phenomenon can be explained by the influence of BRT to the whole urban Hanoi is limited. Although BRT line has speed advantages over ordinary buses, but it may just influence the travel mode choice of people living in BRT corridor. The people living in the areas farther away from BRT line may never need to take BRT due to distance restriction.

In general, weighted average travel time accessibility measure analyses the travel time distribution by both current transport system (Scenario 1 and Scenario 2) and the future scenario after BRT is constructed (Scenario 3). The results indicate that motorcycle still surpass public transport from travel time perspectives and this kind of advantages are difficult to challenge currently or in the near future. But when just focusing on how BRT may impact the original public transport system, it could be found that from the perspective of whole urban Hanoi, the appearance of BRT line may influence people's choice of travel modes when going to work by public transport, but from the results of this measure, the impact that BRT line may bring is really limited.

Table 6 Statistical Summary of Weighted Average Travel Time

Transport Scenario	Mean Weighted Travel Time (Minutes)	Range (Minutes)
Motorcycle	26.0	15 – 46
Walking + Bus	78.2	45 – 208
Walking +Bus +BRT	78.0	45 – 208

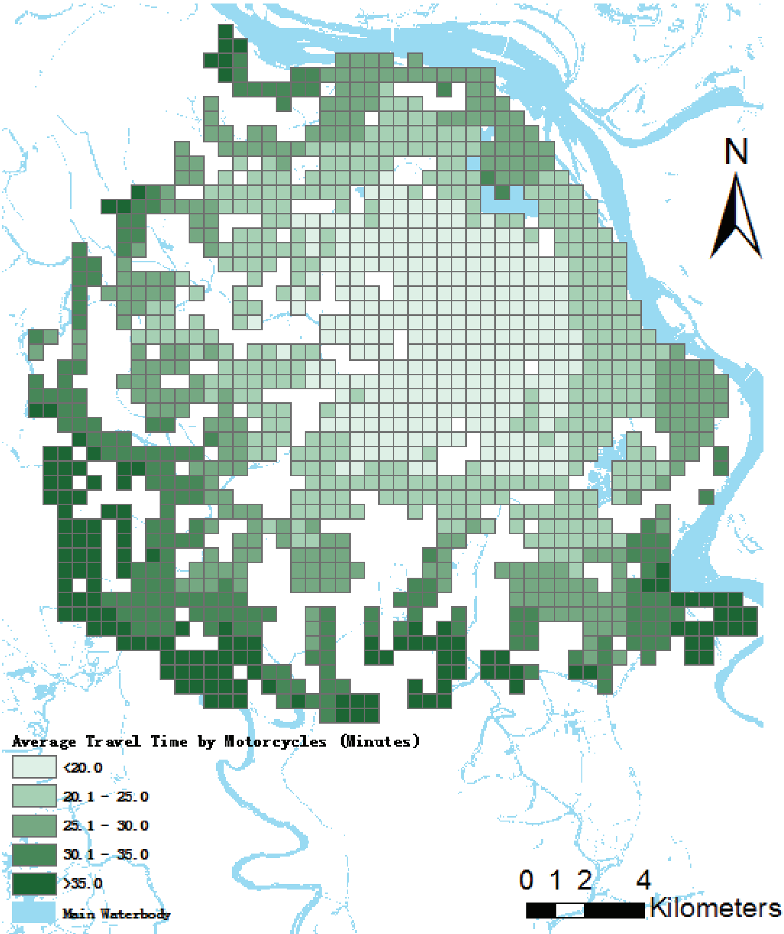

Figure 14 Weighted Average Travel Time by Motorcycles

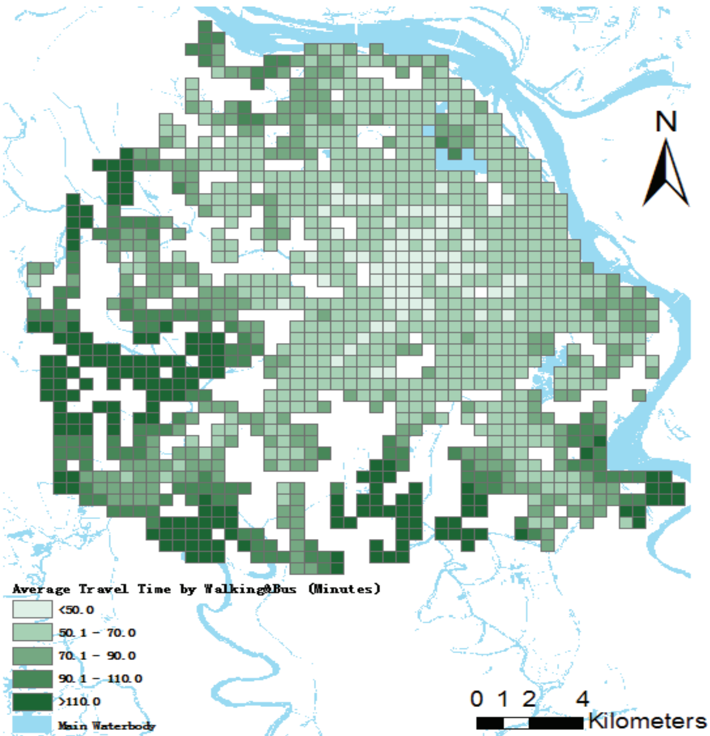

Figure 15 Weighted Average Travel Time of Walking&Bus

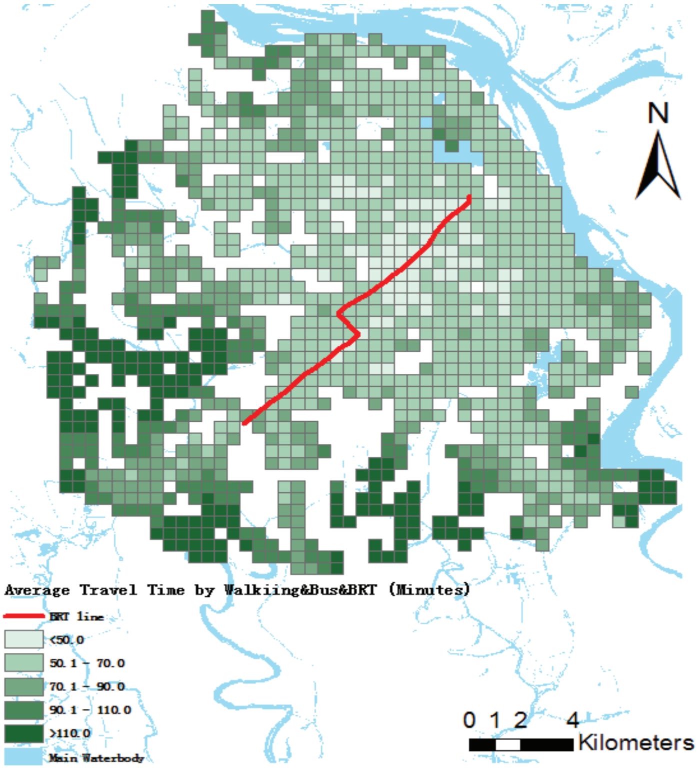

Figure 16 Weighted Average Travel Time of Walking&Bus&BRT

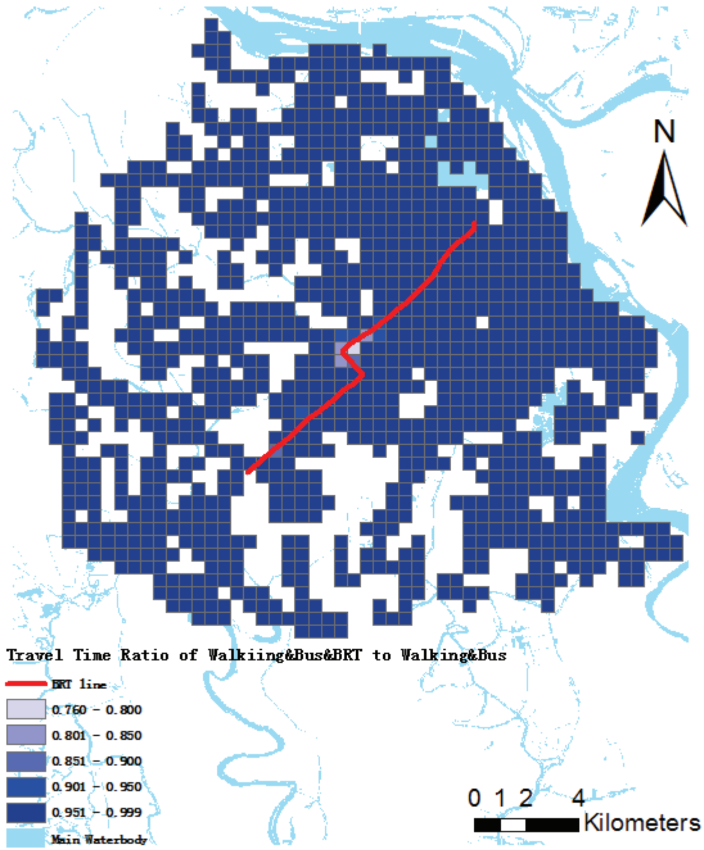

Figure 17 Ratio of Weighted Average Travel Time by Walking&Bus&BRT to Walking&Bus

5.1.2. Measure 2: Potential Accessibility Measure

The potential accessibility measure follows the principle that for each job location (destination), the number of reachable jobs to any residential location (origin) should be discounted by a distance decay effect. The difference of distance decay effect is mainly decided by different travel time for a specific residential location to different job locations. Therefore, the closer (the shorter time) for a residential location to a job location, the more available jobs it could be.

Table 7 Statistical Summary of Potential Job Accessibility Measure

Transport Scenario	Mean Number of Jobs	Range
Motorcycle	68024	867 – 158911
Walking + Bus	1748	1 – 11171
Walking +Bus +BRT	1765	1 – 11173

Table 7 summarises some statistical data of three transport scenarios. Apparently, in terms of potential accessibility measure, the job opportunity of Scenario 1 (Motorcycle) is extremely higher than that of Scenario 2 (Walking & Bus) and Scenario 3 (Walking & Bus & BRT). From the Figures representing potential accessibility distribution of three transport scenarios in Figure 18, Figure 19 and Figure 20, it can be found that urban Hanoi has a mono-centric urban form with which the high accessibility regions are ranging from middle part of urban Hanoi to the North-Eastern part where the city centre locates. Meanwhile, the job opportunities are gradually decreased from city centre to outer areas, and this spatial distribution applies for all three scenarios. This result are similar to the results of weighted average travel time where comparing to other areas, the region closer to city centre have higher potential job accessibilities and lower weighted average travel time. This can be mainly explained by the concentration of road networks in core city centre of Hanoi and this facilitates people's transport conditions, improves general transport accessibility, thus, has a positive influence on the job accessibility.

When comparing the potential job accessibility values between Scenario 2 (Walking & Bus) and Scenario 3 (Walking & Bus & BRT), they both have a quite similar job opportunity distribution when viewing from the accessibility maps and the statistical summary of these two scenarios (Figure 19, Figure 20). Further comparison is made by applying a job accessibility ratio of Scenario 3 to Scenario 2 in Figure 21. When analysing the accessibility ratio between two scenarios, it could be founded that all residential locations of urban Hanoi has benefits of job accessibility increase when BRT line participates in Hanoi urban transport and becomes a choice of people's working travel mode. But this kind of accessibility increase is very slight, only 1%. But the areas which get the most benefits in terms of potential accessibility are 22 out of 1195 residential locations along the BRT line (10%-30% accessibility increase). This may be due that BRT line could influence the travel mode choice of people along BRT corridors, and this kind of impact could positively reduce the travel time of the workers living in these area. While in the potential accessibility calculation, the reduction of travel time of two locations will reduce the distance decay effect between two locations, thus increase the potential job opportunities. But generally, the areas where could get the influence caused by BRT is really limited.

In the whole, from the results of potential accessibility measure, it seems that the influence of BRT on motorcycle is negligible. But when comparing with original public transport system, roughly 2% of residential locations get substantial accessibility benefits (10%-30% increase) and these locations are located along the BRT corridor. This is an evidence to demonstrate that the influence of BRT line mainly lies in the areas along the BRT corridor.

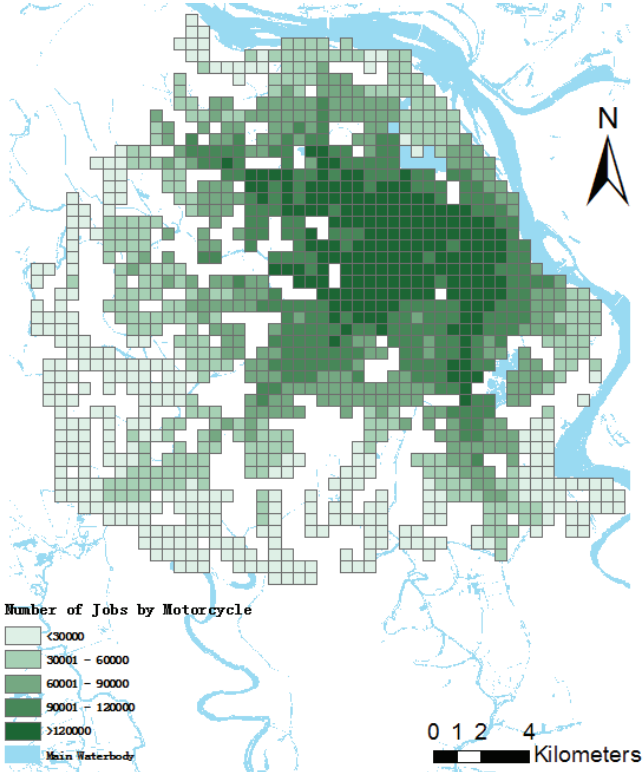

Figure 18 Potential Job Accessibility Measure of Motorcycle

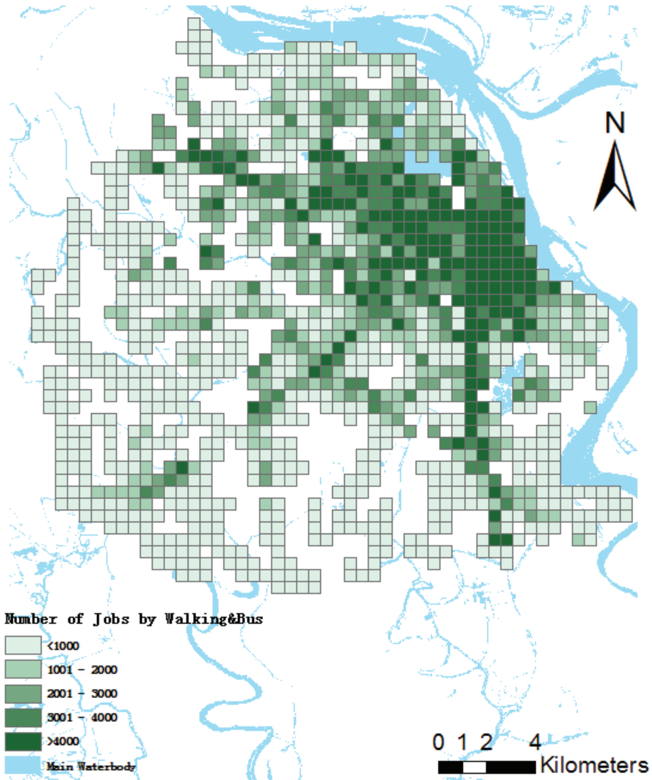

Figure 19 Potential Job Accessibility Measure of Walking&Bus

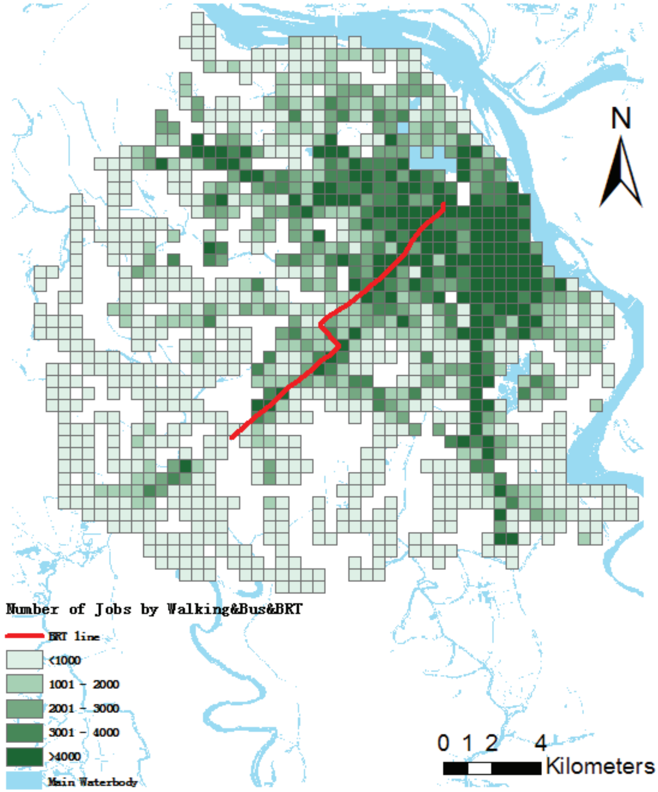

Figure 20 Potential Job Accessibility Measure of Walking&Bus&BRT

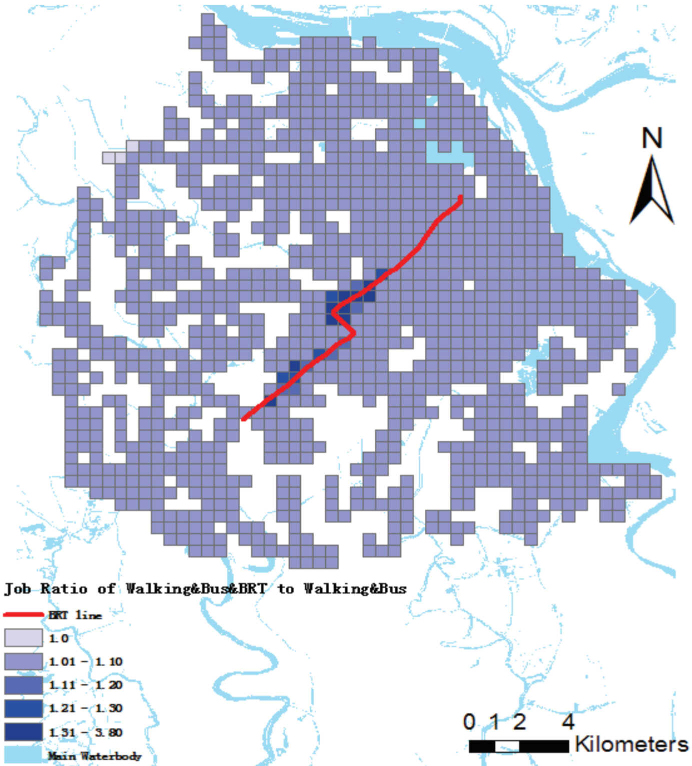

Figure 21 Ratio of Potential Accessibility Measure by Walking&Bus&BRT to Walking&Bus

5.1.3. Measure 3: Competition-based Accessibility Measure

Unlike the traditional accessibility measure, the available jobs of a specific job location to a specific residential location in competition-based accessibility measure are not only meets the number discount from distance decay effects, but also face the competition from other job locations as well as the attractiveness from other residential locations. This makes a phenomenon that the sum of final job accessibility values in all residential locations equals to the number of total jobs in the study area when using competition-based accessibility measure. While for the potential accessibility measure, the sum of final job accessibility values in all residential locations is greater than the number of total jobs in the study area. This is mainly because potential accessibility measure does not consider the competition discount among residential locations and job locations, thus will cause the double count of accessibility calculation in some residential locations. For example, based on the competition-based accessibility model, the job accessibility in Hanoi is represented by job opportunities in all three scenarios. Viewed from the statistical summary of three transport scenarios in Table 8, the mean number of job opportunities are the same, all equalling to 1429. This does not indicate that from the perspective of competition-based accessibility measure, job accessibility level of three transport scenarios are the same. In all three transport scenarios, the total number of jobs in the whole study area is a fix number. While applying competition-based accessibility measure, the job opportunities in one job location to other residential locations will never be doubly counted because the competition component completely eliminate this effect. Therefore, there will be a phenomenon that the job opportunity distribution in all three scenarios is different, but total job opportunities in three scenarios are all equalling to the total number of jobs in the whole study area.

Table 8 Statistical Summary of Competition-based Accessibility Measure

Transport Scenario	Mean Number of Jobs	Range
Motorcycle	1429	1 – 19002
Walking + Bus	1429	1 – 18526
Walking +Bus +BRT	1429	1 – 18526

From the accessibility map of three scenarios (Figure 22, Figure 23, Figure 24), it could be concluded that there is not a distinct concentration of job opportunities in all three scenarios and the high accessibility areas are distributed sparsely. But a general tendency of job opportunity distribution in all the scenarios is the accessibility value of South-Western area is relatively lower than other parts of the urban Hanoi. This can be explained by a lack of sufficient road lines and bus lines among those areas.

After BRT line is constructed, it seems slight difference are made when comparing the job accessibility of BRT with the original public transport system (Figure 25). More specifically, from Figure 25, most areas of urban Hanoi get the benefits of accessibility increase from the BRT line and these accessibility increase are ranging from 1% to 20%. While some small areas experience the slight decrease of accessibility in the study area and especially some residential locations along the BRT corridor. This is a strange phenomenon because BRT is expected to reduce the travel time for work trips along BRT corridor, thus increase the accessibility of those areas. But in terms of competition-based accessibility measure, with the appearance of the BRT line, the mobility along the BRT line will increase because of the speed benefits from the BRT line. Therefore the overall accessibility and attractiveness of the city centre could have a positive influence because one end of BRT line goes into the city centre. Inversely, the balance effect due to the competition component decided that if the total number of job opportunities are fixed, the increase in the job accessibility in one part will definitely cause the decrease in other parts.

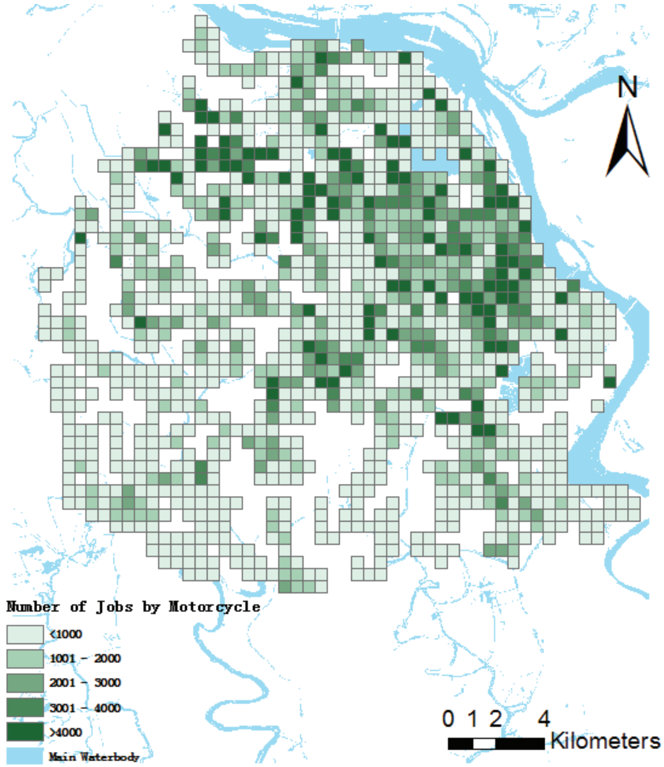

Figure 22 Competition-based Job Accessibility of Motorcycles

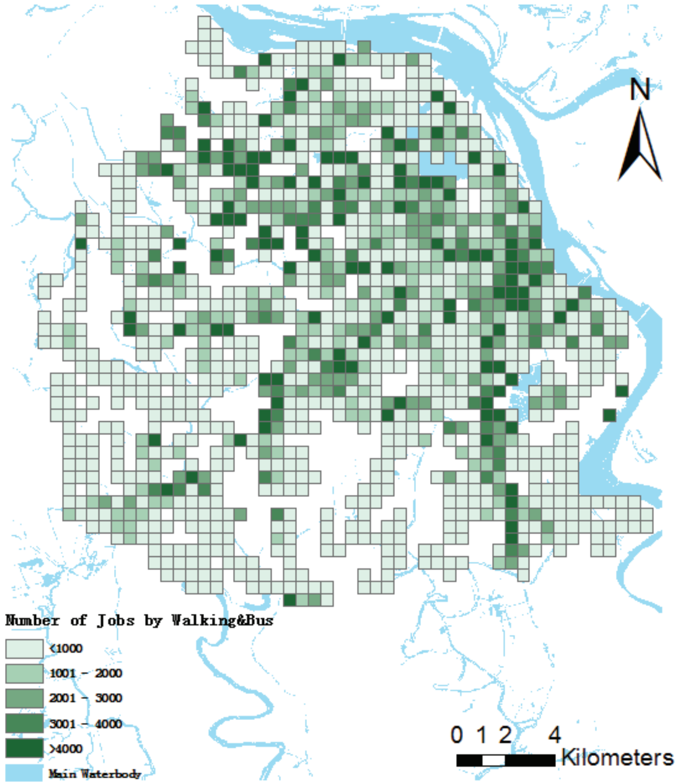

Figure 23 Competition-based Job Accessibility of Walking&Bus

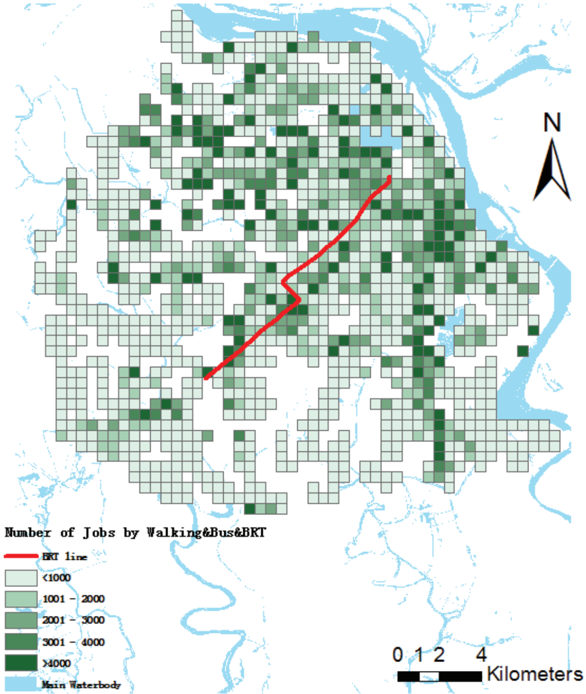

Figure 24 Competition-based Job Accessibility of Walking&Bus&BRT

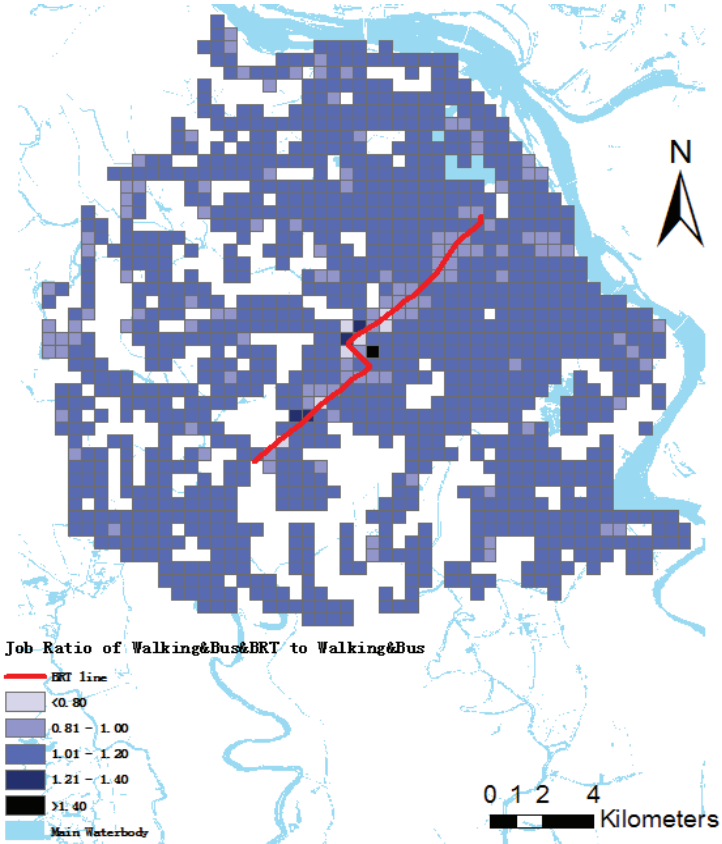

Figure 25 Ratio of Competition-based Job Accessibility by Walking&Bus&BRT to Walking&Bus

5.1.4. Discussion

The accessibility results calculated by three measures reflect that the construction of BRT line could reduce the weighted average travel time and increase the potential job accessibility values for the majority areas of urban Hanoi when comparing to the original public transport. And some residential locations along the BRT corridor get more benefits from time saving and accessibility increase from potential measure. But it seems that there is little difference that the BRT line could make to the usage of motorcycles in terms of either travel time or potential accessibility measure because of relatively higher speed of motorcycles. Meanwhile, for the competition-based accessibility measure, it is hard to reflect the direct influence of the BRT line and the results of the competition-based accessibility measure is difficult to interpret due to its way of calculation. Besides, how competition component could influence the job accessibility distribution in urban Hanoi is hard to explore.

In the whole, in terms of weighted average travel time and potential accessibility measure, it seems that BRT line could bring benefits to the areas along the BRT corridor, but these results are not strongly supportive to reflect the role and benefits of BRT in the Hanoi whole. The contribution of the BRT line to public transport system is still not clear in terms of accessibility. The main reason lies in the study area may be too large so that the contribution of BRT line becomes very small. Therefore, the next step is an exploration of the areas along the BRT corridor.

5.2. Accessibility Analysis for the BRT corridor

5.2.1. Data Preparation and Assumption

The previous study on job accessibility of urban Hanoi could not directly reflect the influence or the potential benefits of BRT line, and one possible explanation is that the study area may be too large. Therefore, this section analyses the job accessibility conditions of a service area along the BRT corridor and the basic assumption is that BRT may have direct job accessibility benefits to the inhabitants living in the service area along the BRT corridor.

The first step is to define the service area along the BRT corridor that BRT is potential to impact. There is a concept called "transit access walking distance" (Alshalalfah & Shalaby, 2007) describing people's acceptable walking distance to take a transit system. And this transit access walking distance varies among the guidelines in different countries. For example, the walking distance guidelines for light rail transit system in Canada ranges from 300-900 meters, compared to 400-800 meters in the USA. The similar study of BRT system indicates a 250 meter walking distance for Bogota and an 800 meter radii for Los Angeles (Jiang et al., 2012).

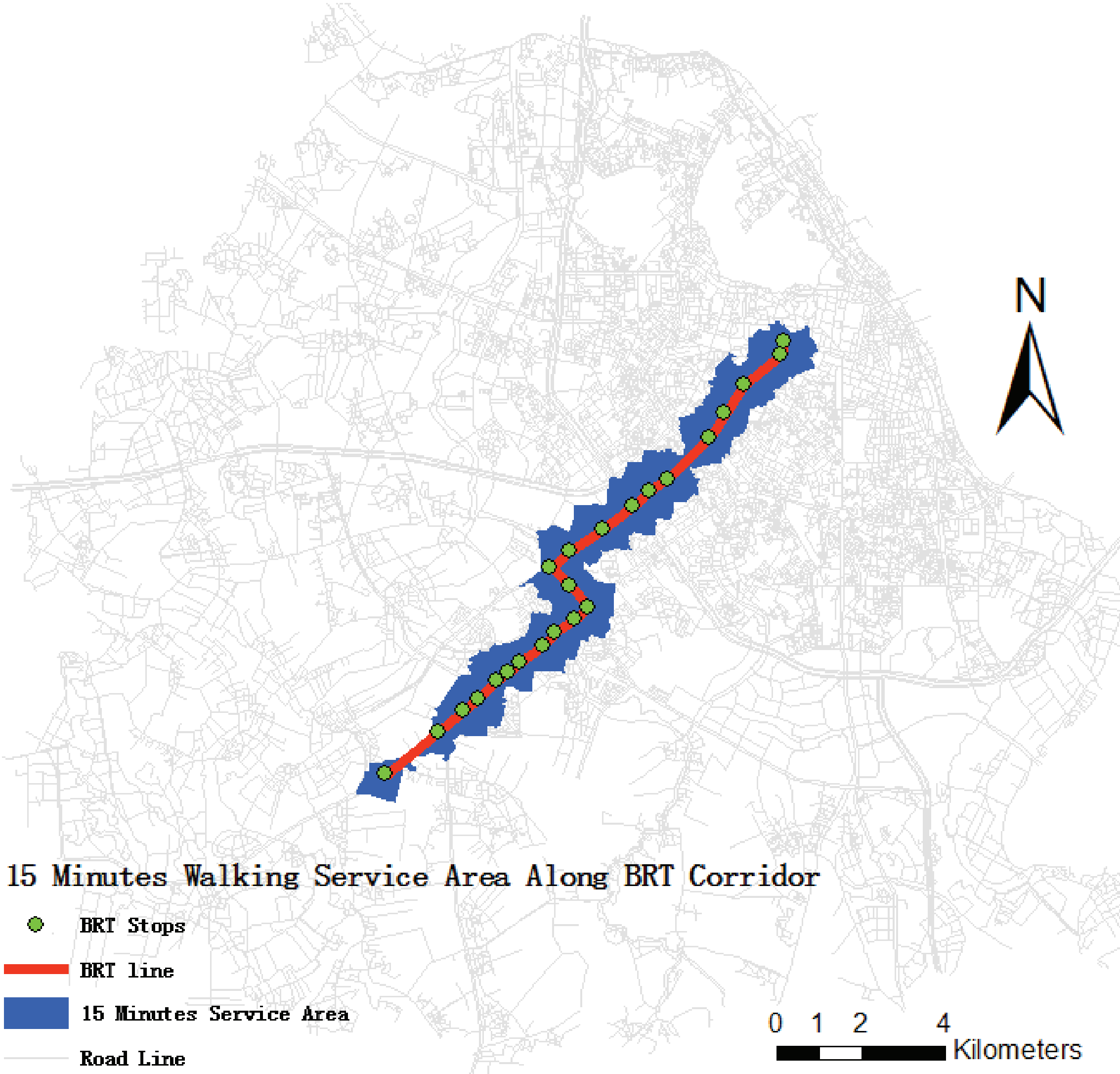

Figure 26 Service Area along BRT Corridor

In this case, based on the assumption of walking speed which is 3.5km/h, a 15 minutes transit access walking distance is chosen for creating the service area along the BRT line. Therefore, a service area is created at an 875m (15 minutes walking distance) walking distance base on Hanoi road networks from the BRT stops (Figure 26). Besides, the original resolution applied for residential locations and job locations for the whole urban Hanoi is 500m*500m which is too large for this service area. Because 500m is more than half of the 875m walking distance threshold and if keeps the original resolution, there will be huge errors for accessibility results. Therefore, for a more accurate analysis of accessibility and reduce the burden of model computation, 100m*100m resolution is chosen for the resolution of residential locations and job locations in this service area along the BRT line. The method of defining of residential locations and job locations in the BRT corridor service areas are the same as described in Section 4.2. The only difference is change the study area to the newly created BRT corridor service areas and use 100m*100m as the resolution instead of 500m*500m. After the data process, there are total 1163 residential locations and 702 job locations in the service area along the BRT corridor.

There are total 4 transport scenarios will be used in this section. The three original transport scenarios which are based on Motorcycle, Walking & Bus and Walking & Bus & BRT will still be tested for the BRT corridor service area. Apart from that, a congestion scenario will be considered for analysing the potential influence of BRT line to the motorcycles. The description of 4 transport scenarios are listed below:

- Scenario 1: Motorcycle
  Before BRT line is constructed, assume that all people use motorcycles to the work place. This scenario will analyze the job accessibility distribution caused by the use of motorcycle in BRT line corridor to see the general influence of motorcycle.

- Scenario 2: Walking + Bus
  Before BRT line is constructed, assume workers will estimate the travel time from living locations to job locations and then decide whether walking directly to job locations or take a bus there depend on the shortest travel time.

- Scenario 3: Walking + Bus + BRT
  After the BRT line is constructed, assuming all people will use walking or bus or BRT to work place. In this scenario, people will estimate the travel time for all possible travel modes among walking, bus and BRT and choose the one or the combination of travel modes which takes the shortest time.

- Scenario 4: Congestion Scenario
  This scenario is a test of BRT influence on motorcycles for assuming a congestion condition in the corridor. Under the congestion condition, the travel speeds of all motorcycles are assumed to have a 30% decrease while the speed of BRT and the frequency of BRT will increase correspondingly. The speed changes of motorcycle and BRT are listed in Table 9. In the previous accessibility results of this research, it seems that BRT line could have little influence on motorcycle in terms of accessibility measures because motorcycle has a relatively higher speed than other public transport. This scenario intends to directly compare the accessibility of motorcycle and public transport (Walking & Bus & BRT) to see to what extent BRT line can influence motorcycle under congestion condition.

Table 9 Traffic Property of Congestion Scenario

Mode	Road Attribute	Speed before congestion (km/h)	Speed after congestion (km/h)	Access before congestion	Access after congestion
Motorcycle	Expressway	45	31.5	N/A	N/A
	National road	40	28		
	Primary road, Province road	35	24.5		
	District road, Local main street, Secondary road	30	21		
BRT		25	28	3 min	1 min

Two accessibility measures are be applied in this section when summarizing from the accessibility results of whole urban Hanoi: the Weighted Average Travel Time and the Potential Accessibility Measure. These two measures could directly reflect the changes in accessibility and the results are easy to interpret. On the contrary, the Competition-based Accessibility Measure is not included in this section because the results of this measure is hard to interpret and could not directly reflect the influence of BRT line

5.2.2. Measure 1: Weighted Average Travel Time

From the statistical data of these 4 scenarios in Table 10, it can be concluded that when compared with other travel modes, motorcycles have dominant advantages in saving travel time from residential locations to job locations due to its high speed character. The travel time distribution maps of motorcycle in Figure 27 shows that the areas have the lowest weighted average travel time value lies in middle part of the service area along the BRT line corridor. And this travel time value increases from centre to the two ends of the BRT corridor where north-eastern part and the south-western part of the BRT corridor have the highest travel time value. This can be accounted for by the well construction of road networks for motorcycles which increases the mobility along the BRT corridor. And the location convenience makes the central parts of the corridor have relatively lower average travel time because the travel time standard deviation of these areas are relatively lower.

The general tendency of weighted average travel time distribution of both Scenario 2 (Walking & Bus) and Scenario 3 (Walking & Bus & BRT) are similar to the result of motorcycles, as shown in Figure 28 and Figure 29. But when comparing the weighted average travel time ratio between these two scenarios, which calculates the travel time ratio of Scenario 2 to Scenario 3 in all residential locations along the BRT corridor. It could be founded that this travel time ratio ranges from 0.48 to 0.98 with a mean value of 0.8 and a standard deviation of 0.1. This result indicates that all the residential locations along the BRT corridor get travel time saving benefits from the BRT line with an average of 20% travel time saving. And the Figure 30 illustrates that the central part of BRT corridor benefits most in terms of weighted average travel time saving, which the most travel time saving could up to 50%.

As for the congestion scenario, weighted average travel time values of public transport (Bus + BRT) and private transport (Motorcycle) are calculated respectively. And a comparison is made by calculating a travel time ratio between public transport and private transport, as shown in Figure 31. As can be concluded that all the ratio values is greater than 1 with a mean value of 2.2 ranging from 1.3 to 3.3. This result shows that although in congestion situation, motorcycle experiences a speed decrease while on the contrary, BRT are forced to raise the speed and frequency but motorcycles still dominates public transport in travel speed.

Table 10 Statistical Summary of Weighted Average Travel Time

Transport Scenario		Mean Weighted Travel Time (Minutes)	Range (Minutes)
Motorcycle		8.7	6.1 – 15.3
Walking + Bus		37.3	26.6 – 58.2
Walking +Bus +BRT		29.9	19.6 – 52.8
Congestion	Motorcycle	12.4	8.7- 21.8
	Walking +Bus +BRT	27.2	17.0 – 50.6

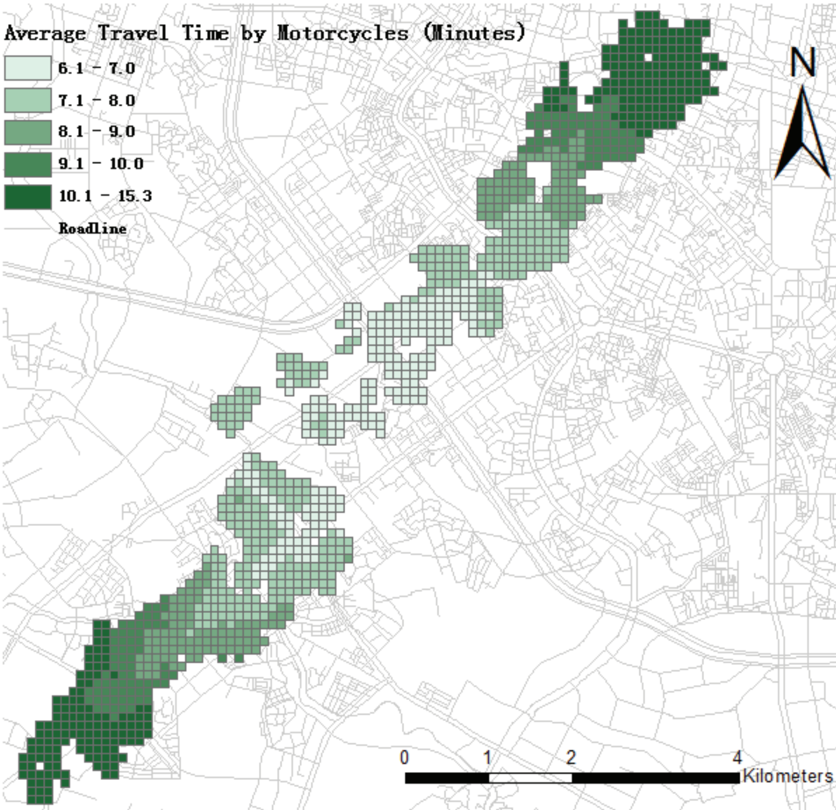

Figure 27 Weighted Average Travel Time along BRT Corridor by Motorcycles

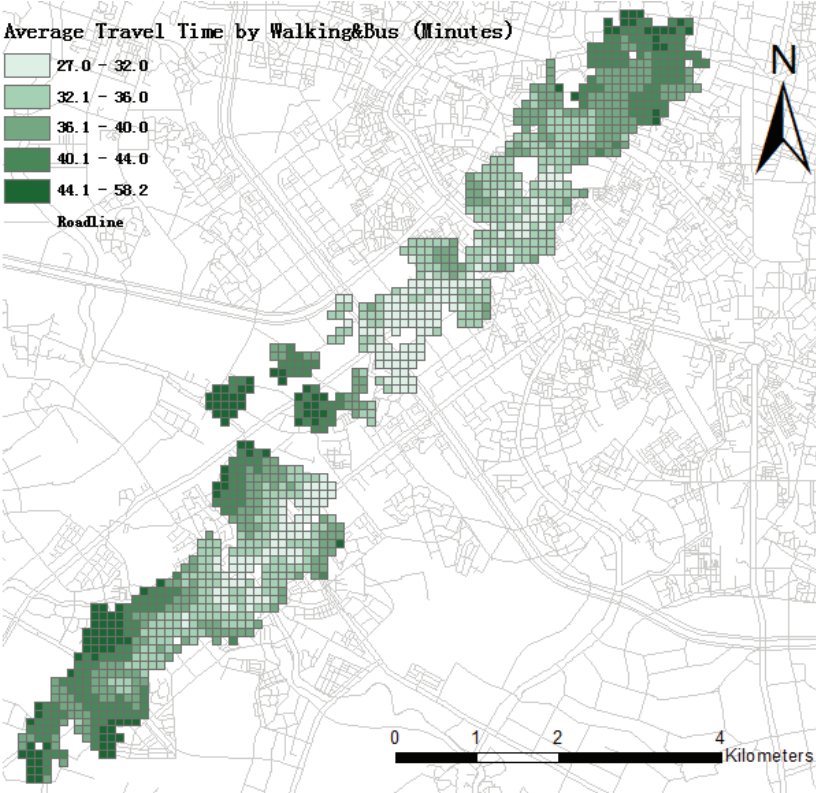

Figure 28 Weighted Average Travel Time along BRT Corridor by Walking&Bus

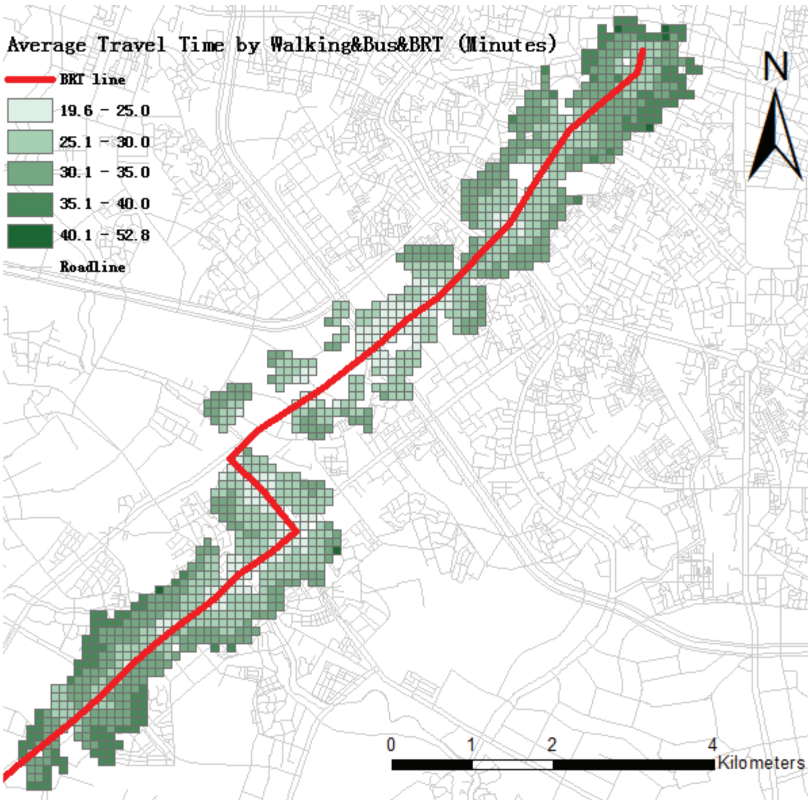

Figure 29 Weighted Average Travel Time along BRT Corridor by Walking&Bus&BRT

Figure 30 Ratio Weighted Average Travel Time along BRT Corridor by Walking&Bus&BRT and Walking&Bus

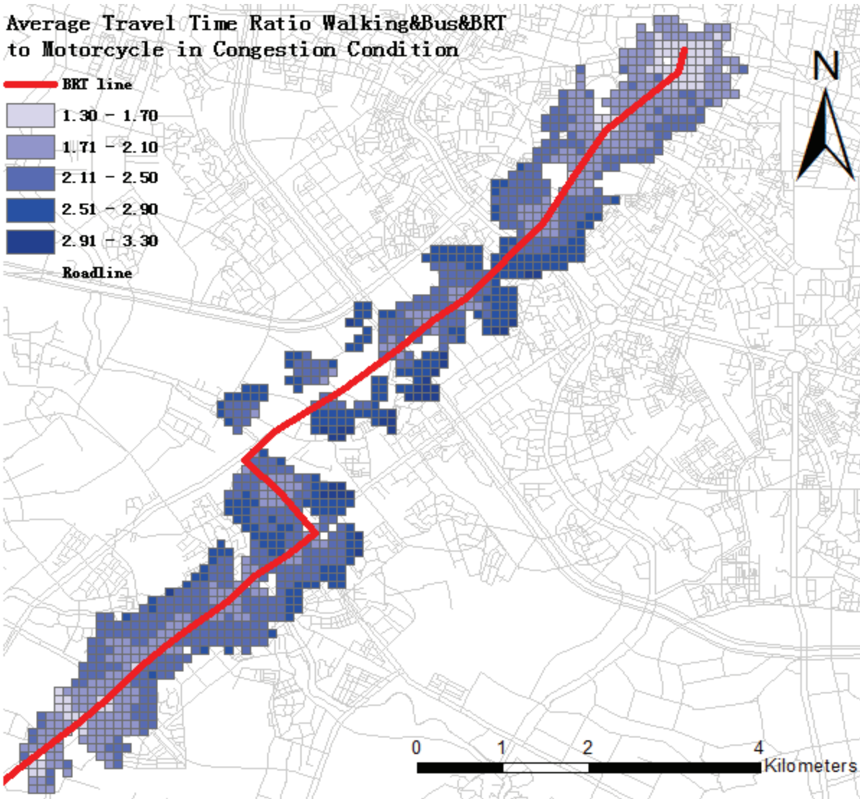

Figure 31 Ratio Weighted Average Travel Time along BRT Corridor by Walking&Bus&BRT and Motorcycles in Congestion Scenario

5.2.3. Measure 2: Potential Accessibility Measure

From the statistical summary of 4 scenarios by potential accessibility measure in Table 11, motorcycle still has the highest accessibility values when comparing with public transport along the service area of BRT corridor. The average number of job accessibility in motorcycle scenario is more than the twice of other public transport scenarios. This is a normal phenomenon because potential accessibility measure is largely depends on distance decay effect, and this decay effect is mainly decided by travel time. And the motorcycles have apparent travel time advantages over other travel modes. Besides, the region with the highest accessibility values is located in the middle part of the BRT corridor (Figure 32) which is similar to the distribution of weighted average travel time measure. This matches the property that travel time plays a dominant role in these two measures. Similar distribution happens in Scenario 2 (Figure 33) and Scenario 3 (Figure 34).

On the other hand, a comparison is also made to see the accessibility effect of BRT line on the corridor by creating potential job accessibility ratio of Scenario3 (Walking & Bus & BRT) to Scenario 2 (Walking & Bus). As can be seen from Figure 35, all the ratio values are greater than 1 with an average of 1.1, indicating that the job accessibility of all the residential locations are improved with an average of 10% proportion due to the role of BRT line. Comparing with original bus system, the appearance of BRT line provides more travel choices for people living along the BRT corridor and shortens the travel time for some home-work trips along the BRT corridor. This time saving decreases the distance decay effect between some residential locations and job locations, thus, increase corresponding job accessibilities.

While for the congestion scenario, from Figure 36, it could be summarized that the accessibility values of public transport still could not exceed the accessibility of motorcycles even in congested traffic. The range of accessibility ratio is from 0.48 to 0.78 with a mean value of 0.58. Apparently, in terms of travel time, public transport may take less time than some trips if travelled by motorcycle due to the speed changes of congestion, but this kind of influence to motorcycle is quite limited.

Table 11 Statistical Summary of Potential Job Accessibility Measures

Transport Scenario		Mean Number of Jobs	Range
Motorcycle		45757	30248 – 67686
Walking + Bus		19278	14566 – 27662
Walking +Bus +BRT		21264	15437 – 30732
Congestion	Motorcycle	38283	25307- 56630
	Walking +Bus +BRT	22273	15899 – 32453

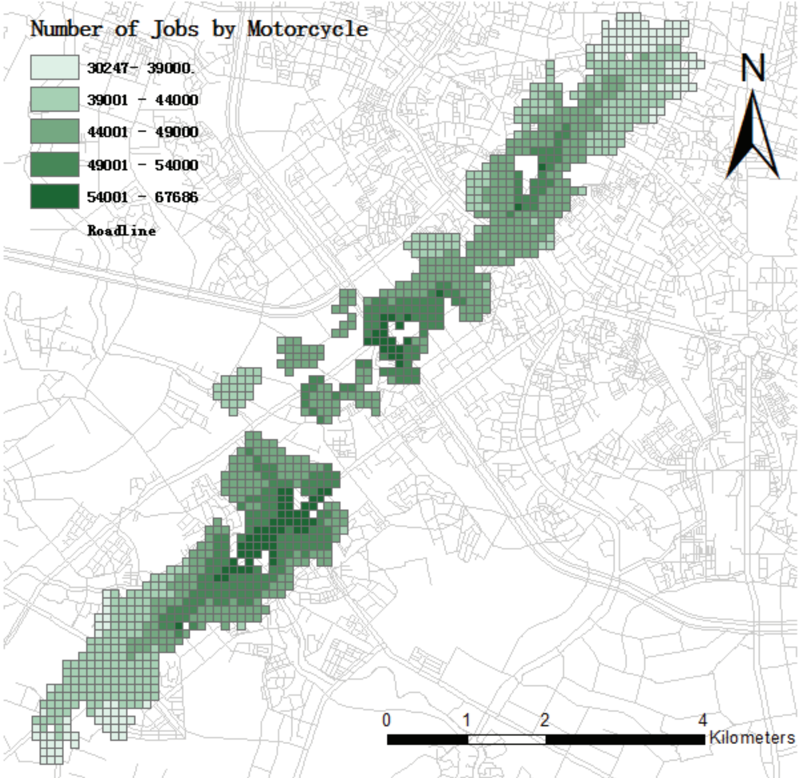

Figure 32 Potential Job Accessibility Measure along BRT Corridor by Motorcycles

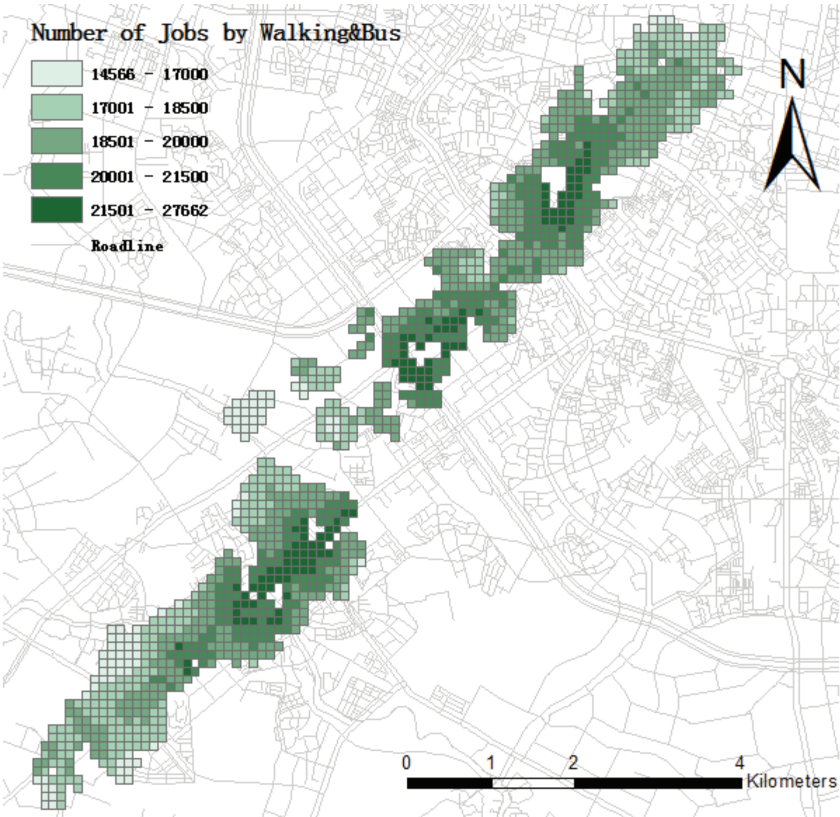

Figure 33 Potential Job Accessibility Measure along BRT Corridor by Walking&Bus

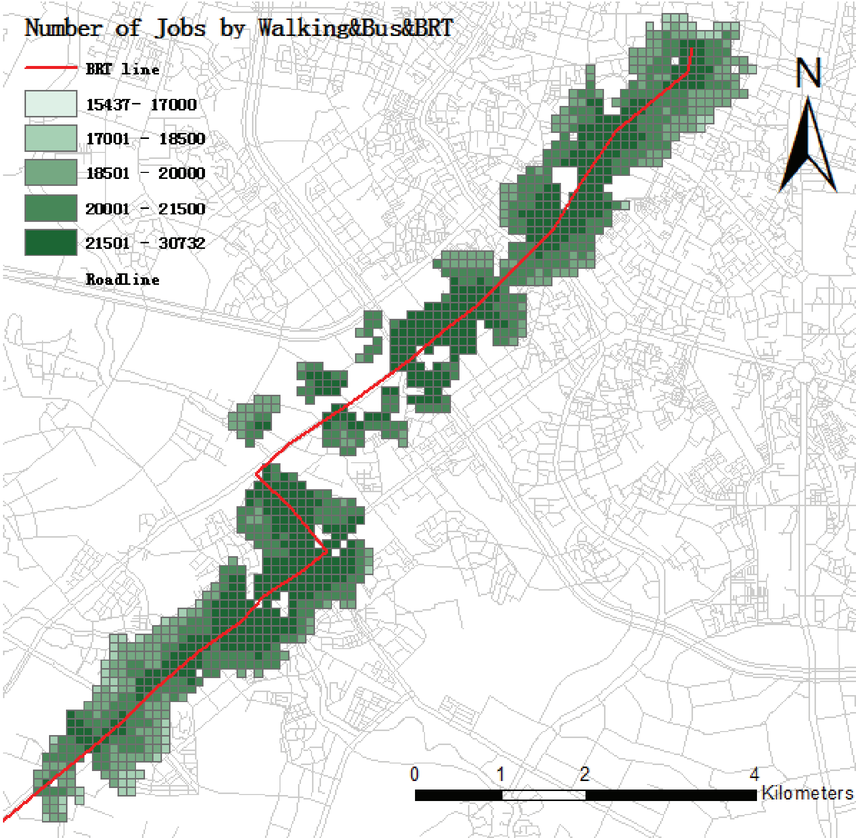

Figure 34 Potential Job Accessibility Measure along BRT Corridor by Walking&Bus&BRT

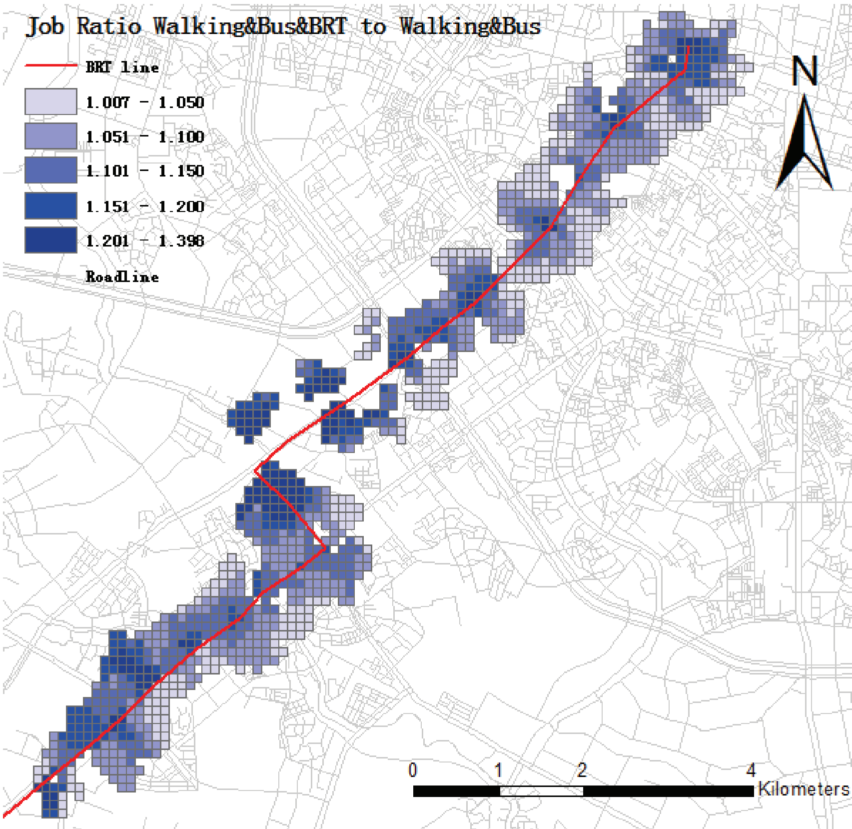

Figure 35 Ratio Job Accessibility along BRT Corridor by Walking&Bus&BRT to Walking&Bus

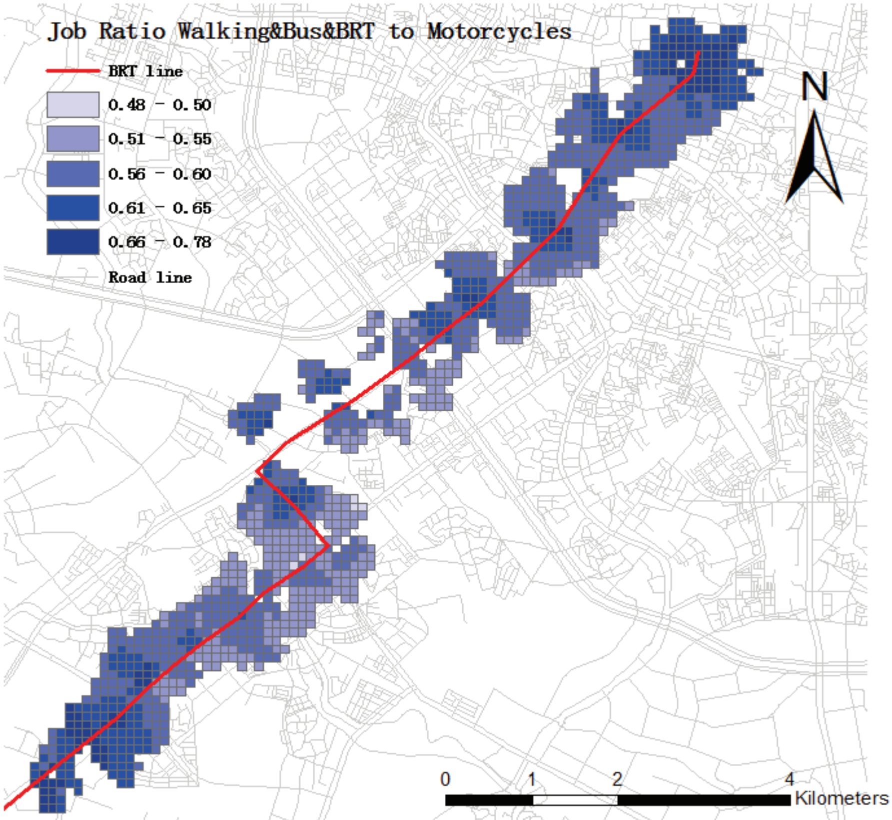

Figure 36 Ratio Job Accessibility along BRT Corridor by Walking&Bus&BRT to Motorcycles in Congestion Scenario

5.2.4. Discussion

In the whole, after cutting the study area by using a service area along the BRT corridor, it could be concluded that BRT line will make benefits to the people living in BRT corridor in terms of measuring both weighted average travel time and the potential accessibility value. When comparing the job accessibility of Walking & Bus & BRT scenario with Walking & Bus scenario in these two measures, they both get different degree of accessibility benefits. For weighted average travel time measure, all residential locations along the BRT corridor are estimated to have an average reduction of 20% travel time for home-work trips. While for potential accessibility measure, all residential locations along the BRT corridor are estimated to have an average increase of 10% in job accessibility values. Although private transport (motorcycles) still surpass public transport in both accessibility measures due to speed advantage, but these difference is acceptable. And if social, economic and convenient factors are all taken into consideration in people's choice of travel modes, the construction of the BRT line may promote certain modal shift from motorcycles to public transport along the BRT corridor.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusion

The main objective of this research is using accessibility to evaluate the benefits of a Bus Rapid Transit line in urban Hanoi. Literatures on the evaluation of BRT system and the commonly used accessibility measures are reviewed. Three job accessibility measures are selected and used in this case for analysing the job accessibility conditions in the study area. The weighted average travel time is found to be suitable for evaluating both infrastructure efficiency and the importance of job activities. The potential accessibility measure is particularly focus on the interaction between residential locations and job locations and it could reflect on the function and efficiency of the transport networks. However, competition-based accessibility measure is also preferred because it is a comprehensive job accessibility measure considering the factors like job diversity, distance decay effect and competition component among both workers and jobs.

To achieve the main objectives, the study firstly applied the three selected accessibility measures in analysing the job accessibility situation in whole urban Hanoi area. Three transport scenarios are built and compared to see the accessibility changes between the current transport situation and the future situations after the BRT line is constructed. The results indicate that when measuring from weighted average travel time measure and potential accessibility measure, motorcycle always has the lowest weighted average travel time and highest potential accessibility value compared with public transport (bus & BRT). But if just see the influence of BRT on the original public transport system, the whole urban Hanoi will get accessibility improvement in terms reduction of weighted average travel time and increasing of potential job accessibility values. But these improvement is very slight and only some residential locations along BRT corridors obtained relatively higher accessibility improvement. Meanwhile, these improvement could not directly reflect how BRT line could influence the job accessibility conditions of urban Hanoi because the study area is too large to see the impact of BRT line. On the other, competition-based accessibility measure is proved to be not very suitable for evaluate the benefits or efficiency of an infrastructure system because the interference of competition factor will cause the job accessibility distribution changes rather than reflecting on accessibility value changes.

Due to the job accessibility analysis of urban Hanoi have limited effects on evaluating the benefits of the BRT line. The study continued by using a service area along the BRT corridor and applying weighted average travel time measure and potential accessibility measure to evaluate the contribution of the BRT line. Four transport scenarios are utilized this time. The results indicate that the job accessibility values in the areas along the BRT corridor are effectively improved due to the construction of BRT line when comparing with the original public transport system. But motorcycle, as the dominant travel mode in Hanoi, still surpass public transport system in terms of job accessibility.

In the whole, some concluding remarks are summarized from this research:

1) The proposed BRT line in urban Hanoi could improve the job accessibility values in most areas of urban Hanoi, but the most benefit groups are people living along the BRT corridor.
2) BRT line may influence the transport situation as well as social activities in urban Hanoi, but these impact is limited, mainly lies in the areas along the BRT corridor.
3) The appearance of the BRT line is hard to challenge the dominant role of motorcycles in travel modes of urban Hanoi, but it may promote some modal shift from motorcycles to public transport.
4) Compared with the original public transport system, the appearance of the BRT line is estimated to have an average reduction of 20% weighted average travel time and an average increasing of 10%

potential job accessibilities for the areas along the BRT corridor.

5) Weighted average travel time and potential accessibility measure are two effective accessibility measures for evaluating the benefits of a transport system from job accessibility perspective, and competition-based accessibility measure is not very suitable for reflecting the efficiency of a transport system.
6) Job accessibility is a suitable indicator for measuring the benefits of a transport system such as a BRT line, but the selection of job accessibility measures should be based on the actual situations of the study area and the purpose of the study.

6.2. Recommendations

Three recommendations are provided for the further study of the Hanoi BRT line.

Firstly, this research does not include bicycles and cars as private travel modes because motorcycles are the predominant transport mode in Hanoi, other private modes only takes a little share of the travel needs. Bicycles are increasingly popular in Hanoi and can be a potential feeder to the BRT system. Therefore, it is worth to consider cycling as an important travel mode.

Secondly, jobs are calculated by overall jobs in each job location in this study, but does not distinguish different types of jobs according to social-economic factors. Therefore, the future research could consider a detailed classification of job types based on social-economic factors like educational level, age or sex, and match these job types only available for certain groups of people. This kind of classification could further explored which groups of people benefit most from BRT line in accessibility perspective and which groups have the least benefit.

Thirdly, the resolution for job locations and residential locations in the whole study area is chosen as 500*500 meters while for the service area along the BRT corridor, these resolution is increased to be 100*100. The future research could further increase the resolution, thus could improve the accuracy of accessibility results.

As an important conclusion in this research, the influence of BRT line is limited, mainly lies in the areas along the BRT corridor. Besides, from the accessibility results of the whole urban Hanoi, the South-Western part of urban Hanoi has relatively higher weighted average travel time and relatively lower potential accessibility value. This shows that the job accessibility of these areas is low while the road networks and bus lines are not sufficient in these areas. Therefore, a suggestion is given to the Hanoi municipality to considering an alternative BRT in the south-western part of urban Hanoi. This measure may effectively improve the accessibility conditions of those areas.

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