Measuring Modal Accessibility Gap and Modal Emission Gap to evaluate the Bus Rapid Transit line: A case study in Hanoi

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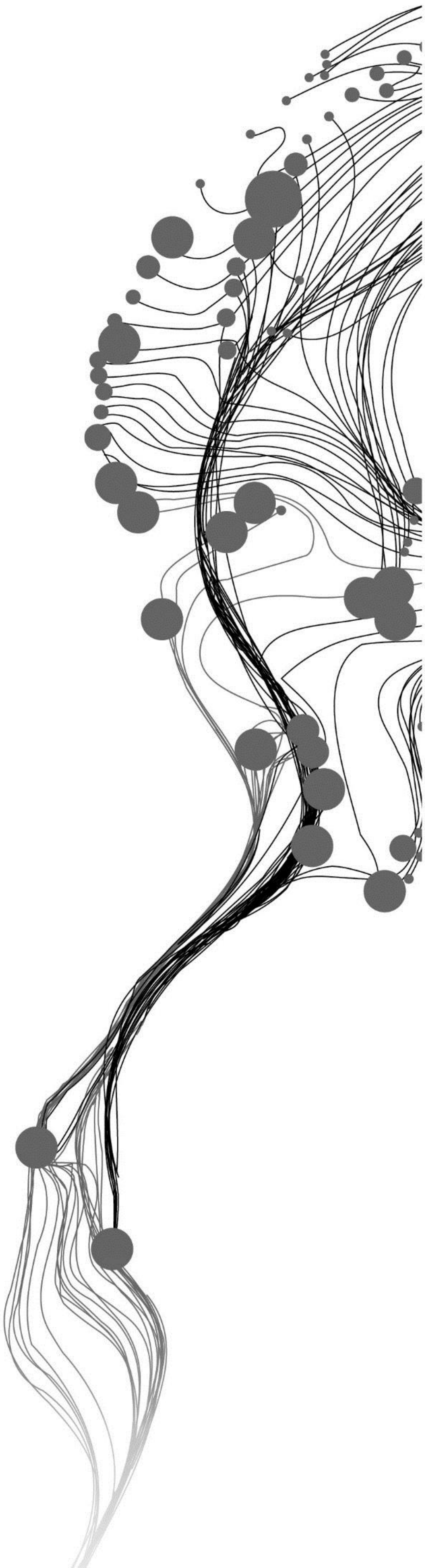

Measuring Modal Accessibility Gap and Modal Emission Gap to evaluate the Bus Rapid Transit line: A case study in Hanoi

TINGTING WEI
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Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
Specialization: Urban planning and management

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ABSTRACT

Rapid development of urban cities and the fast increase of vehicle ownership have led to frequent traffic congestion and environment problem in the capital of Vietnam, Hanoi. Especially the highly dominant motorcycle use is a major pollution which affect people's health. In order to improve this situation, Hanoi government proposed a new Bus Rapid Transit (BRT) line which has the characteristics of high quality, high capacity, and rapid transit system. This research aims to evaluate this BRT line to see the benefit of it in terms of accessibility and CO_2 emissions.

The research applies Modal Accessibility Gap (MAG) and a new proposed indicator Modal Emission Gap (MEG) to evaluate the effect of the BRT line in urban Hanoi. Here MAG is a comparative indicator for job accessibility, MEG is a comparative indicator for vehicle CO_2 emissions. A potential measure is used to compute job accessibility for MAG. And a 4-step transportation model is applied to estimate the motorcycle CO_2 emissions for MEG.

The results indicates that the BRT line has a positive effect on the mode shift from motorcycle to the BRT and CO_2 emissions reduction. The effect is amplified if congestion occurs. The study also confirmed that the MAG and MEG are effective indicators in evaluating the benefit level of a public transport system within specific areas in terms of job accessibility and CO_2 emission, even if they benefit a little.

Key words: Modal Accessibility Gap (MAG), Modal Emission Gap (MEG), Job accessibility, 4-step transportation model

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1. INTRODUCTION

1.1. Background

In recent decades, the rapid development of cities and the fast increase of motorised vehicle ownership have led to frequent traffic congestion and environmental problems in urban areas. Sustainable development is one of the themes of the world today (Xing, Liang, & Xu, 2013). One important part of the sustainable and social development for a city is the transport system, which also the mainly contributor to carbon emissions (Fengbo & Jianlan, 2011). Due to the need for environmental protection and energy-saving, developing the public transport system has become a preferential trend in transportation planning (Yang, Chen, & Yu, 2008, Xing et al., 2013).

Bus Rapid Transit (BRT) is an integrated, flexible and high performance transit system which contributes to sustainable transportation system (Mahadevia, 2013). BRT is an integrated rubber-tired system of facilities, services, and amenities that collectively improves the speed, reliability, and identity of bus transit with potentially lower capital and operating costs (Ancora, Nelli, & Petrelli, 2012). A BRT system could be integrated with other transport services to allow effectiveness and efficiency improvements. In Ahmedabad for example the application of BRT system have reduced congestion level. Meanwhile, the travel mode changes induced by BRT have also contributed to an improvement of air quality, reduction of air pollution in the city especially along the BRT (Nugroho, Fujiwara, & Zhang, 2010).

BRT has been successfully planned and implemented in many cities. The Hanoi government has recognized the significance of increasing the utilization of public transport system which could promote urban mobility and bring social and environmental benefits to Hanoi. Especially in Hanoi city about 70% people use motorcycle (ALMEC Corporation, 2007). A new BRT line was proposed running through the centre of urban Hanoi in 2007 (The World Bank, 2007). This BRT line is expected to bring benefits to the people of urban Hanoi such as the decrease of travel time, the reduction of fuel consumption and greenhouse gases emission, the mitigation of traffic congestion, and also the improvement of the living environment. Besides, compared to other public transport systems, BRT has advantages like fast delivering, comfortable and cost-effective urban mobility as well as rapid and frequent operations (Filipe & Macário, 2013).Therefore, understanding and evaluation of the proposed BRT is needed.

1.2. Justification

Previous studies have used various indicators for assessing BRT systems. The conventional approaches focus on the amount of ridership, travel time savings, increased speed (Nelson, 2006, Lund & Clark, 2008). Also, Tiwari & Jain, (2012) proposed the evaluation of BRT using accessibility which measured the number of relevant destinations that can be reached and safety of different type of roads. There are also some evaluation indicator utilized for measuring BRT system such as influence on social economy, influence on traffic function, or effect on environment and the influence on resources utilization (Hidalgo, Pereira, Estupiñán, & Jiménez, 2013, Deng & Nelson, 2013). Operational efficiency and technical performance are also considered indicators(Xing, Liang, & Xu, 2013).

The accessibility difference between various transport modes is referred to as Modal Accessibility Gap (MAG) (see the concepts in literature review 2.3), has been proven to be an effective indicator for assessing transport development (Kwok & Yeh, 2004). This research will use two indicators to assess the impact of BRT (1) MAG will be used to compare the accessibility difference between private transport and public transport and (2) the impact of the BRT on vehicle carbon emissions will also be studied, this research will propose an indicator termed Modal Emission Gap (MEG) which means the emission difference in different transport scenarios.

1.3. Research Problem

Accessibility, is a performance indicator for assessing transport policies, sustainable development and spatial distributions of urban people and activities (Ha, van den Bosch, Quang, & Zuidgeest, 2011). It has been used by Hansen, (2009) to analyse how people's travel behaviour changed because of a changing transport system. Tiwari and Jain, (2012) proposed evaluation of BRT involving accessibility which measured number of relevant destinations that can be reached. Examining the mitigation vehicle emission is an effective way for evaluating sustainability of the transport system (Imaseki, (1998), Fengbo & Jianlan, (2011) Nejat, & Hayhoe, 2014). Deng & Nelson, (2013) evaluated the impact of BRT system on air quality. However, there are few research which combine accessibility and vehicle emission to assess the BRT system. Thus, the key issue that will be addressed in this research is to combine accessibility and vehicle emission to assess the BRT system.

1.4. Objectives

(1) General Objectives:
The main objective of this study is to assess the effect of a proposed Bus Rapid Transit line in Hanoi in terms of job accessibility and CO_2 emissions.
(2) Sub-Objectives:
Sub-objective 1: To develop a MAG approach to generate a comparative job accessibility indicator at local and global level[1] for motorcycle and public transport system with and without BRT.
Sub-objective 2: To develop a MEG approach to generate a comparative CO_2 emissions indicator at local and global level for motorcycle with and without BRT.
Sub-objective 3: To analyse the effect of BRT in terms of MAG and MEG.

1.5. Objectives and Questions

Sub-Objectives	Questions
1. To develop a MAG approach to generate a comparative job accessibility indicator at local and global level for private and public transport system with and without BRT.	(1)What is the spatial distribution of residential locations and job locations?
	(2)What is the job accessibility of different travel modes?
	(3) What is the MAG between public transport and private transport before and after the construction of BRT line at local level and global level?
2.To develop a MEG approach to generate a comparative CO_2 emission indicator at local and global level for motorcycle with and without BRT.	(4) What is the motorcycle volume on the road segment?
	(5) What is the potential CO_2 emissions saving from the BRT line?
	(6) What is the motorcycle MEG between with and without BRT transport scenario at local and global level?
3. To analyse the effect of BRT in terms of MAG and MEG.	(7)What is the effect of BRT in terms of MAG and MEG?

[1] Global level: using statistics numbers to represent overall situation.
Local level: using maps to show the situation of different areas.

1.6. Conceptual Framework

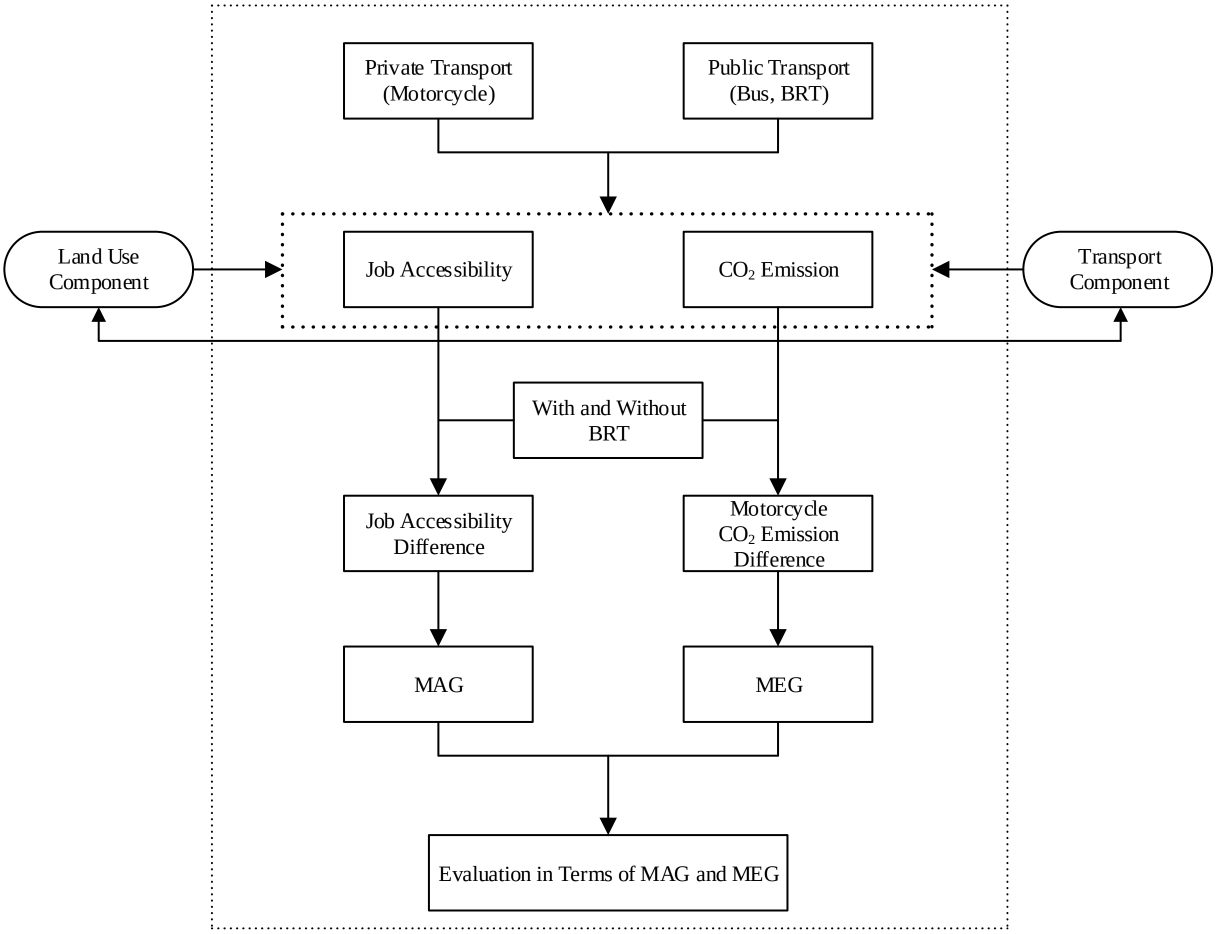


Figure 1-1 Conceptual Framework

The main task is to use MAG and MEG to evaluate the expected effects of the Bus Rapid Transit line. The conceptual framework shown in Figure 1-1, has been designed to show the major components and their interactions. Accessibility is a performance indicator for assessing transport policies, sustainable development. The influence of accessibility and CO_2 emissions are based on two components; land use component consisting of the amount, quality and spatial distribution opportunities such as jobs supplied at each destination and the demand for these opportunities at origin locations. Transport component reflect the disutility for individual like travel cost. These two components contribute to measure the job accessibility and CO_2 emission.

This evaluation can be separate into two parts, assessing BRT system (1) using MAG to evaluate the impact of BRT. MAG between public transport and private transport indicates the effect of BRT in the whole transport system. The change after the construction of BRT can reflect the level BRT contributes to improving job accessibility. (2) The impact of the BRT on vehicle carbon emission will also be studied, this research will propose an indicator termed MEG which means the CO_2 emission difference in different transport scenarios. The change in vehicle carbon emission will be investigated to reflect the emissions saving from BRT line and the place where get benefit will also be reflected.

1.7. Research Design

Research Data

The data has been prepared by Mr. Nguyen Ngoc Quang, PHD candidate at the Department of Urban and Regional Planning and Geo-information in ITC.

Research Methods

Modal Accessibility Gap

The MAG will be used in sub-objective 1. This research will develop on adapted MAG model for Hanoi. First stage is adapting the MAG model with the existing data, then exploring the data and define the distribution of residential locations and job locations (Question1), after computing the job accessibility of different transport mode (Question2), the next step is using the adapted MAG model to show the accessibility gap between public transport (without BRT) and private transport, also the accessibility gap between public transport (with BRT) and private transport is reflected on(Question3).

Modal Emission Gap

The MEG will be used in sub-objective 2. First step for MEG is to estimate the CO_2 emissions of motorcycle on each road segment by implementing the 4-step model (Question4). Then, in order to estimate the emissions after constructing BRT, an existing survey data will be applied in spatial distributing the mode shift from private transport to BRT (Question5). The next stage is using MEG model to show the emission gap in different transport scenarios (Question 6).

1.8. Research Phases

In order to achieve the research objectives, there are four major phases to be done as shown in Figure 1-2.
1) The first phase is to identify research problems to generate general research methods, have an overview of the data and Hanoi.

- Have an overview of the study area, which is urban Hanoi, especially focus on population, jobs, and transportation.
- Have an overview of the existing accessibility models, select proper accessibility measure and prepare related parameters. Perform the basic data analysis and select the useful data and parameters which are the utilized in the research process.

2) The second phase aims at preparation of residential data (land use data) and job data (social-economic data), build road network (transport data) for modelling accessibility and estimating CO_2 emissions.

- Based on the available data, defining spatial distribution of residential locations and job locations.
- Prepare data and parameters for MAG model and MEG model.

3) The third phase is to implement MAG model, implement MEG model

- Base on the data in the previous phase defined, using potential measure to calculate job accessibility between public transport and private transport, then calculate MAG.
- Based on the transport data defined, calculate the CO_2 emissions for every cell, then calculate MEG.

4) In the fourth phase, result based on different scenarios will be analysed, there will be an evaluation of how the BRT system would influence access to job opportunities and mitigation of CO_2 emissions in Hanoi. Several steps could be proposed as below:

- MAG analysis, MEG analysis.
- Interpretation of the analysis results.
- Evaluation the benefits of BRT line in Hanoi.

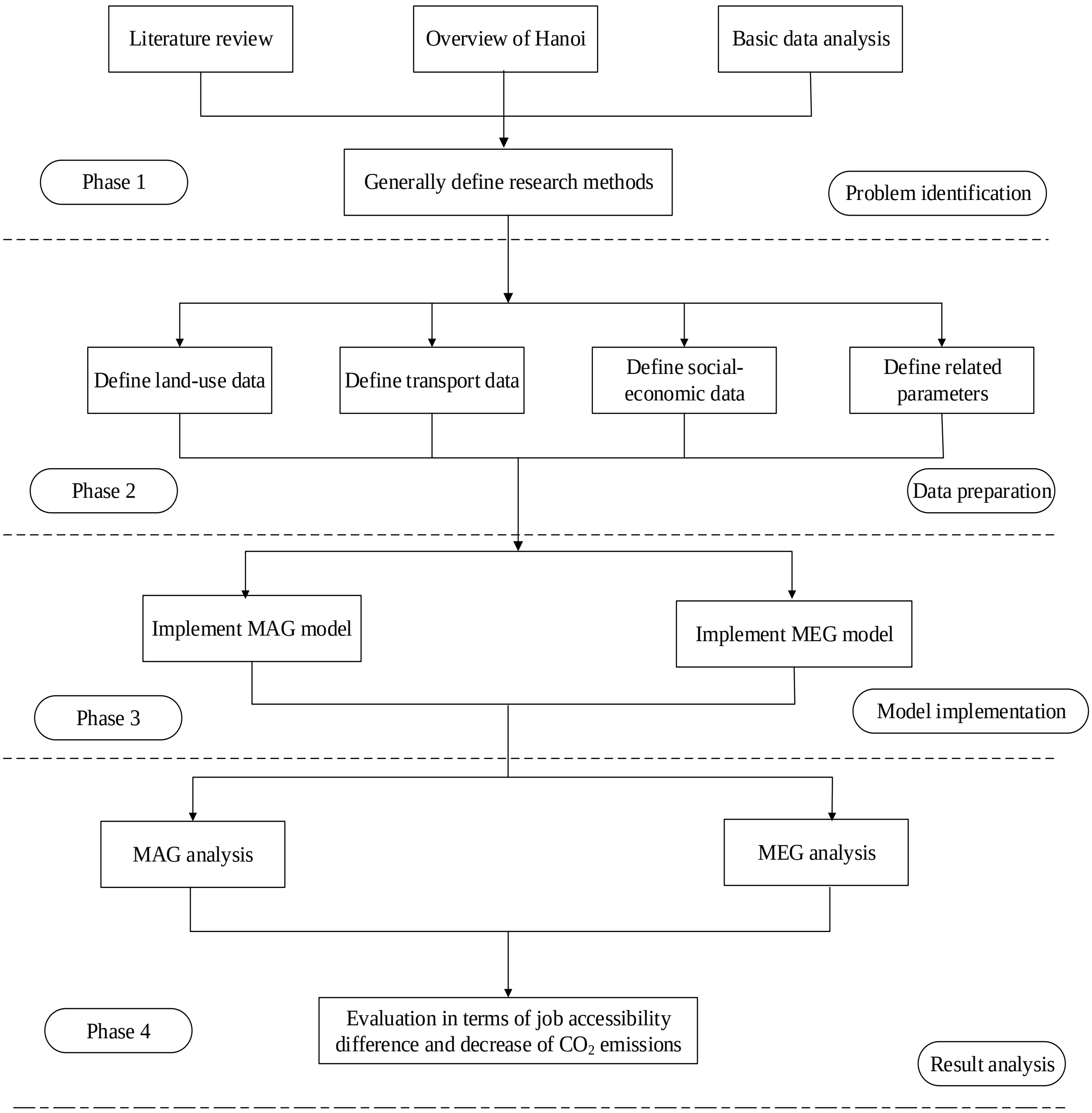


Figure 1-2 Research Phases

1.9. Structure of thesis

This thesis includes six chapters. Below is a brief description of each chapter.

Chapter One: Introduction

This introductory chapter shows the background, research problems, and objectives with the corresponding questions, research design and structure of thesis.

Chapter Two: Literature review

This chapter reviews literature on existing accessibility models, MAG, the previous study to estimate CO_2, and concepts relevant to this thesis. Critical discussion will be made. The specific arguments on the strength and weakness of these models.

Chapter Three: Study area and Data

This chapter introduces the study area for this research, and some explanation of the existing data.

Chapter Four: Methodology

This chapter includes the methodology for preparing socio-economic data and transport data, also the methodology for generate the indicator MAG, MEG.

Chapter Five: Result and Analysis

The contents of this chapter includes two part: MAG analysis, MEG analysis .The result will be used for evaluating the impact of BRT line.

Chapter Six: Conclusions and Recommendations

This chapter provides conclusions for this research and according to the limitations of this research, there are also some recommendations for the further study.

2. LITERATURE REVIEW OF MEASURING ACCESSIBILITY AND ESTIMATING CO_2 EMISSIONS

This chapter has three sections. The first section introduces the characteristics of BRT. Second section provides the definition of accessibility and reviewed concepts, pros and cons for contour measure, potential measure. Then provides some studies and methods for compare the accessibility difference. Third, it reviews and evaluates some related methods for estimating CO_2 emissions, two main categories included, 4-step model and network model. For the second and third section, the discussion of selection of relevant methods are included.

2.1. Bus Rapid Transit System

Bus Rapid Transit is a high-quality, high-capacity rapid transit system. It has been successfully implemented in many countries, like America, Australia, and Indian. The main features of BRT systems include: bus priority at intersections; specialized alignment in the centre of the road; stations with off-board fare collection; station platforms level with the bus floor (The Bus Rapid Transit Standard, 2014).

There are many benefits can be derived from BRT system. Firstly, it is easier to commute by providing frequent service into residential areas and commercial areas. Secondly, it can run faster than ordinary buses and have the same speed with light rail (Deng & Nelson, 2013). BRT systems can give commuters convenience by in time service. Thirdly, BRT systems most apply rubber-tired, low-floor vehicles with wide passageway. In that way it is easy to board and comfortable to get on and off. For the transportation system and the state, BRT system is a choice which is less cost public transport because of the special design. It has the advantage of existing rights-of-way and areas for stations to make the system efficiency and decrease the environment impact. By using of clean fuel vehicles and the decrease in private traffic and congestion, BRT systems contributes to protect the environment. In addition, by providing high quality service made people feel more comfortable, BRT potentially increases overall transit ridership especially along the BRT corridors (Nugroho et al., 2010).

2.2. Concepts of Accessibility

Accessibility has been explored by many researchers in several ways. Hansen (1959) defined accessibility as 'the potential of opportunities for interaction p387'. After that Martin, (1976) proposed 'the ease with which any land-use activity can be reached from a location using particular transport system p18', and 'a property of individuals and space which is independent of actual trip making and which measures the potential or opportunity to travel to selected activities p92' (Morris, Dumble, & Wigan, 1979) is also a well-known definition. Geurs & van Wee (2004) consider accessibility as 'the extent to which the land-use transport system enables (groups of) individuals or goods to reach activities or destinations by means of a (combination of) transport mode(s) p128'. Although, different research have diverse definitions, the main idea is ease of the frication to reach the destinations. In this research, accessibility means people by different transport modes from their home to the job places.

Accessibility Measures

In order to have a better understanding of accessibility measures, the following sections review some commonly used accessibility measures.

Contour Measure

Contour measure is one of the easiest measures to measure accessibility. It only count the number of opportunities reached in a certain travel time (or distance) (Handy & Niemeier, 1997) such as number of hospitals within 30min drive of a origin. After that the total number of opportunities from every reachable destination for one origin is calculated. As the potential destinations in the time threshold are equal weighted, therefore the number of opportunities or destinations are more important than the distance.

The advantage of this measure is that it is easy to interpret and operate for researchers and policy makers. It only counts the number of opportunities available for every origin. One of the disadvantage of this measure is that it gives every destination equal weight as long as it is located within a certain travel distance or time threshold. It doesn't consider the opportunities outside of this threshold. Another shortcoming is that this measure is very sensitive to the threshold.

Potential Measure

The potential measure is an extension of contour measure and derived from the gravity model for trip distribution, It weights opportunities by a distance decay function or impedance factor (Geurs & van Wee, 2004; Langford & Higgs, 2006; Ha, van den Bosch, Quang, & Zuidgeest, 2011). It is widely used in urban and geographical studies as it overcomes some of the theoretical shortcomings of contour measure like incorporates assumptions on a person's perceptions of transport by using a distance decay function. The formula is expressed as follows (Geurs & van Wee, 2004):

$$\boldsymbol{A_i = \sum_{j=1}^{n} D_j f(c_{ij})} \quad (1)$$

$$\boldsymbol{f(c_{ij}) = e^{-\beta c_{ij}}} \quad (2)$$

Where $\boldsymbol{A_i}$: accessibility value from origin zone i;

$\boldsymbol{D_j}$: the number of opportunities in destination zone j;

$\boldsymbol{c_{ij}}$: travel time, distance, or cost from origin zone i to destination zone j;

$\boldsymbol{f}$ ($\boldsymbol{c_{ij}}$): distance decay effect from origin zone i to destination zone j;

β: the parameter of impedance function.

The potential measure focus on the interaction between origin and destination, the closer from origin to opportunities, the more it contributes to accessibility; the larger the opportunity, the more it contributes to accessibility(Handy & Niemeier, 1997).

This paragraph discusses about the pros and cons of potential measure. One of the advantages is to consider the opportunities of all destinations. The travel time can't limit the reachable destinations but the time can discount the opportunities from the destination. Another advantage is easy to calculate and interpret because it measures the probability of available opportunities from each destination for every origin as well as easy to visualization. Also this measure has the advantage of easily computed using existing land-use and transport data. For the weakness, as everyone has different travel behaviours, it is difficult to define the decay function.

Table 2-1 Studies for Comparing Accessibility by Different Travel Modes

Study	Study area and Unit of analysis	Accessibility method	Approach of comparing different accessibility	Elements involved	Results
Blumenberg (2004)	Los Angeles: neighbourhood	Contour measure within 30min	Ratio of job accessibility by car to job accessibility by public transport	(1)Travel mode(private transport: car; public transport: bus, tram) (2) Travel time threshold (3) Job distribution	People travel by car can access more jobs than people travel by public transport
Kwok & Yeh (2004)	Hong Kong, China 253 TAZs in 1991 and 1996	Potential accessibility taking demand-side factor into account	Standardized Value of accessibility difference between public transport and private transport (MAG)	(1) Travel mode(private transport: car; public transport: bus, railway) (2) Parking fare, tolls (3) Job, shop, school distribution	(1)Accessibility of private transport is higher than public transport. (2)People can get better accessibility by public transport in 1991 than 1996
Kawabata, (2007)	Boston: 986 TAZs in 1990 and 2000 San Francisco: 1099 RTAZs	Potential accessibility taking competition on demand side with time threshold 30 min, 45 min, and 60 min	Standardized Value of accessibility difference between public transport and private transport (MAG)	(1)Travel mode(private transport: car; public transport: tram) (2) Travel time threshold (3) Job distribution	(1)Lower job accessibility by public transport than by car (2) The accessibility gap between public transport and car increased in both cities
Benenson, et al. (2010)	Tel Aviv metropolitan area, Israel	Access area, and Service area with time threshold 30 min, 40 min, 50 min , 60 min	Access area ratio, and the Service area ratio	Travel mode(private transport: car; public transport: bus) (2) Travel time threshold (3) Job distribution	Large gaps between car-based and transit-based accessibility in Tel Aviv metropolitan area
(Gao, 2014)	Arnhem Nijmegen city region: 448 TAZs	Contour measure within 15min,30min,45min; Potential measure	Standardized Value of accessibility difference between public transport and private transport (MAG)	(1)Travel mode(private transport: car; public transport: bus, train) (2) Travel time threshold (3) Job distribution	Compared with other travel modes, car shows the absolute advantage in both contour measure and potential measure

2.3. Studies for Comparing Accessibility Difference

As Table 2-1 shows Blumenberg, (2003) made a ratio of accessibility value between the different transportation modes to show that people travel by car can access more jobs than people travel by public transport. The research by Kwok & Yeh (2004) investigated the job accessibility gap of Hong Kong in 1991 compared with that in 1996 to examine the transport development trend by making use of MAG. The similar accessibility differentials between transport modes are applied in (Kawabata 2007; Gao 2014). Kawabata (2007) examined the spatial variations of job accessibility difference between travel by car and public transit as well as the temporal changes in this difference in the metropolitan areas of Boston and San Francisco. While, Gao (2014) used MAG to make the comparison between car and other travel modes, then explore scenarios to reduce the MAG value in Nijmegen. Also, Benenson, et al.(2010) studied accessibility gap between different travel modes by introducing the concept of access area and service area as some extension on accessibility measure in Tel Aviv metropolitan area, Israel.

Researchers have been focus on the access of job opportunities by different methods. Based on accessibility measure applied in research, all of these researches used potential measure, further, two categories are classified: contour measure (Blumenberg, 2004; Gao, 2014) and potential measure (Kwok & Yeh, 2004; Kawabata, 2007; Benenson, et al.2010; Blumenberg, 2004; Gao, 2014). Moreover, some studies taking demand side into account. (Kawabata, 2007) consider the competition that employers compete for workers on demand side, while the generalized cost of travel include parking fare, tolls is taken into consideration in calculating accessibility by (Kwok & Yeh, 2004). Particularly, Kawabata (2007) use a combination of contour measure and potential measure, which represent the potential measure with time threshold. In addition, another method proposed by Benenson, et al.(2010) considers the access area rather than opportunity with time threshold.

Modal Accessibility Gap

In terms of the approach of comparing different accessibility shows in Table 2-1 three categories can be divided: MAG value (Kwok & Yeh, 2004; Kawabata, 2007; Gao, 2014), car/ transit accessibility ratio (Blumenberg , 2004), access area ratio and service area ratio (Benenson, et al. 2010). MAG value is standardized value of accessibility difference between public transport and private transport ranged from -1 to 1, the result is easy to interpret comparing different transport situation. (Kwok & Yeh, 2004) compared MAG value in 1991 and 1996 in Hong Kong, (Gao, 2014) constructed different scenarios to investigate whether the change of land use and transportation can affect the accessibility, MAG value shows comparable outcome. Besides, car/ transit accessibility ratio is Ratio of job accessibility by car to job accessibility by public transport, it is a straightforward method. But it isn't standardized, the ratio vary too widely to compare and interpret. For access area ratio and service area ratio, it based on travel time and time of the day, outcome value is comparable and easy to interpret within time threshold.

Assessing sustainable transport development can be based on the consideration of energy-efficient difference between public transport and private transport, The concept of MAG was first proposed by Kwok & Yeh, (2004). The MAG is calculated by finding the difference between the accessibility of transit and private transport, which is in turn determined by accessibility to opportunities such as the number of population, jobs, shops, and schools by transit and private transport as well as consider the demand-side factor and generalized cost of travel include parking fare, tolls, etc. Figure 2-1 shows the range of the MAG. The formula is as follows:

$$\mathbf{MAG} = \frac{A^T - A^P}{A^T - A^P} \tag{3}$$

Where A^T: accessibility value of transit;

A^P: accessibility value of private transport;
T : Transit (public transport);
P : Private transport.

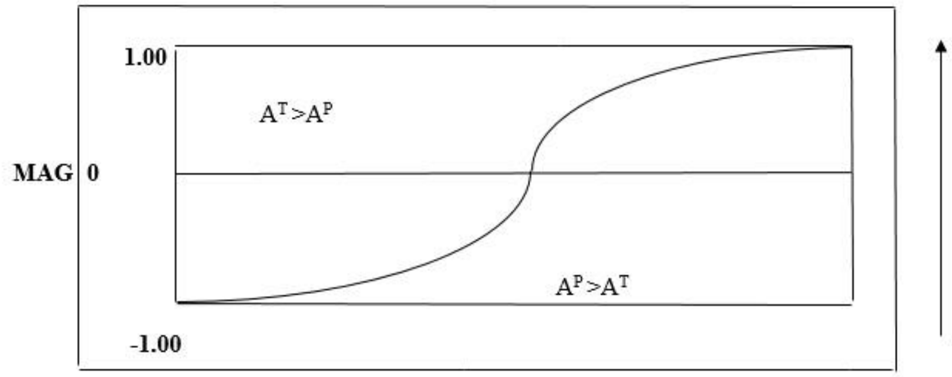


Figure 2-1 Range of the Modal Accessibility Gap (Kwok & Yeh 2004)

As is shown in Figure 2-1,the direction of the arrow means more people can get better accessibility by public transport, The MAG ranges between -1 and 1, a city with a MAG of -1 has no transit services and private transport therefore has an absolute advantage over public transport. In order to plan for an eco-friendly city, accessibility by transit should be promoted over accessibility by private transport. Between -1 and 1, the higher the value means more people can get better accessibility by public transport. Theoretically speaking, for eco-friendly transport development, we should aim at pushing the MAG away from -1 towards 1.

2.4. Selection of Accessibility Measure for Comparing Accessibility Difference

It is important to select proper accessibility measures in relation to evaluate the impact of BRT from a job accessibility difference perspective. The selection should depends on two points: first, the method should be available in comparable manner between the changes of job accessibility in Hanoi city before and after construction of the BRT line. Second, the method should be suitable for analysing the case of Hanoi based on current available data and could easily be interpreted.

This research will use an adapted MAG model which derived from the study by Kwok & Yeh (2004), this adapted MAG model uses potential measure without considering the cost of travel include parking fare, tolls, etc. to assess the impact of BRT in Hanoi. The commonly used accessibility measure for MAG is contour measure and potential measure from previous study, but contour measure only takes the same weight to each opportunity in a certain threshold without considering the opportunities beyond the threshold and without evaluating the combine effect of land-use and transport component. While, the traditional potential measure is a widely used accessibility measure in transport analysis because the results of this measure shows how transport system affects the attractiveness of certain locations. The attractiveness of certain locations are discounted by distance decay effect. The potential measure overcomes some of the theoretical shortcomings of the contour measure: the measure evaluates the combined effect of land-use and transport elements, and incorporates assumptions on a person's perceptions of transport by using a distance decay function (Geurs & van Wee, 2004). What's more, the study by Ha et al., (2011) found that traditional potential measure is suitable for public and decision makers as it has less data requirements and easier to understand as well as interpret in Hanoi. Therefore, this research will use adapted MAG model which involved traditional potential accessibility measure to do the accessibility analysis.

2.5. Vehicle Emission Estimation

Studies for Estimating Vehicle Emission

Vehicle emission estimating have been used mostly to allow decision makers to manage local air quality effectively (Shamsul 2006; Nejadkoorki et al., 2008; Juntunen et al., 2011; Brondfield et al., 2012; Zahabi et al., 2012). Shamsul (2006) examined the potential impact of a BRT corridor on air quality. Besides, predict CO_2 emission for an urban area by a micro-scale approach can examine how these emissions might be affected by various management strategies (Nejadkoorki et al., 2008). Also, focusing on the traffic emission related to the location of the facilities is a way of assessing the optimal locations of retail facilities (Juntunen et al., 2011). Independent model validation is crucial for building confidence among policy makers and ensuring that policy changes result in the intended emissions reductions, Brondfield et al. (2012) proposed an independent on-road measure for validation, this kind of measure can be easily applied in other metropolitan regions with limited data. Zahabi et al. (2012) tries to Estimate the potential impact of emerging green technologies (introduction of hybrid buses, electric commuter trains, and fuel efficient cars) compare their impact with those related to urban form (UF) and transit supply (TS) initiatives.

From Table 2-2. It is known that most researchers have paid attention on vehicle type, travel speed, travel distance and emission factor in estimating vehicle emission. Some researches (Shamsul, 2006; Nejadkoorki et al., 2008; Brondfield et al. 2012) take traffic volume into account to estimate vehicle on each segment of road. Time of the day is another element considerable for modelling traffic emission, the traffic flow is largely different in relation to whether it is peak-hour or not, likewise the increase of the intensity would result in the growth of traffic, the prolongation of peak-hours and the change of trip modes (Nejadkoorki et al., 2008; Brondfield et al. 2012). The work by Juntunen et al. (2011) also consider road categories, the average driving speed on disparate type of roads is different thus average CO_2 emission values are defined for different types of roads. The study of Zahabi et al. (2012) involves fuel consumption which can estimate the CO_2 emission of different types of vehicles, for example, cars, hybrid buses, electric commuter trains.

Different methods are used in estimating the vehicle emission. The application in research, two categories are distinguished: the 4-step model and network model. For 4-step model the number of trips from each origin and destination will use what kind of travel mode will be predicted as well as traffic emissions on different routes in the network. While, the network model is essentially a topological model describing the connectivity relationships between the segment of the network, as well as the impedance associated with each of the segments. The road network model proposed by Juntunen et al. (2011) consider not only the travel time as an impedance attribute, but also contains information about the CO_2 emissions which are accumulate along the fastest routes related with different types of roads.

Four-step Transportation Model

The Four-step Model is usually applied to predict the flows with the links of a particular transportation network as a function of the lane-use activity system that generates the travel (Janelle, Hanson, & Richmond, 1995). It describes the flow of traffic between locations to allow for forecasting and analysing future vehicle movement. The four-step transportation model is shown in Figure 2-2, which includes four sub-models: Trip generation, Trip distribution, Mode choice and Route assignment. The main idea of this model aims to estimate travel pattern form of individuals making choices about whether to travel (trip generation), where to travel (trip distribution), which mode to use (modal split) and which route to use (route assignment)

Table 2-2 Studies for Estimating Vehicle Emissions

Study	Study area and Unit of analysis	Elements involved									Methods	Results
		Type of vehicle	Travel speed	Time of the day	Travel distance	Emission factor	Traffic volume	Number of street segments	Fuel consumption	Road categories		
Shamsul (2006)	Klang Valley, Malaysia : 241 TAZs	√	√			√	√				(1) 4-step transportation model (2)Emission mapping	There is huge difference in CO emission on the BRT corridor. With BRT the CO emission saved 30.5%
Nejadkoorki, Nicholson, Lake and Davies (2008)	Norwich, UK: 91 TAZs	√	√	√	√	√	√	√			(1)Simulation and Assignment of Traffic in Urban Road Networks (SATURN) model.	The annual spatial distribution of CO_2 emission across the city for 2003.
Juntunen, Antikainen, Kotavaara, & Rusanen (2011)	Oulu region, Finland: grid consisting of 1 * 1 km-wide cells	√	√		√	√				√	Network model	The 8 different retail location gains different CO_2 values. The CO_2 values for the whole study area.
Brondfield, Hutyra, Gately, Raciti, & Peterson, (2012)	Boston and Worcester MPOs: grid consisting of 1 * 1 km-wide cells	√	√	√		√	√				4-step transportation model	Estimating the on-road CO_2 emissions in the whole area at the urban regional scale in Boston.
Zahabi, Miranda-Moreno, Patterson, Barla, & Harding, (2012)	Montreal:42094 households	√	√		√	√		√	√		(1) Traffic assignment model (2)GHGs models	The average emissions for the total household travel GHG, the central neighbourhoods emit less and as one goes towards the suburbs the GHG emission of the households increase.

Trip Generation

The modelling process begins with generating an estimate of the amount of trips expected in the urban system usually at the zonal level or traffic analysis zones (TAZ). This step on the base of socio-economic data and land-use description of the activity system, then the number of trips generated in different zones of the study area can be predicted.

Trip Distribution

For the second step, person trips are distributed amongst different origins and destinations. It determines flows and allocates the trips generated in origin zones to destinations in the study area and the travel cost between them. A popular method used in trip distribution model is the gravity model, as this method modelled the spatial interaction between origin and destination.

Modal Split

The third step is for reflect trips from each origin and destination will use what kind of travel mode. Here trips are apportioned to various modes of transport based on travel cost and preferences.

Route Assignment

The last step trip assignment is to predict traffic volumes on different routes in the network, which means each mode uses certain route between origin and destination zones. From traffic volumes, noise, pollutant emissions can also be predicted. The commonly applied traffic assignment algorithm is All-or-Nothing assignment (AON), which assumes that people will choose a shortest route from origin to destination regardless of congestion effect.

Data needed in 4-step model

- Supply data : Type of service provided (e.g. local road, express-bus service, train service); Design speed; Capacity (function of number of lanes or public transport vehicles)
- Demand data: Volumes of use by time of day, trip purpose; Volumes of use by time of day, trip purpose; Attributes of users that relate to levels of use and methods of use (e.g. motorcycle ownership, household size, income, age)

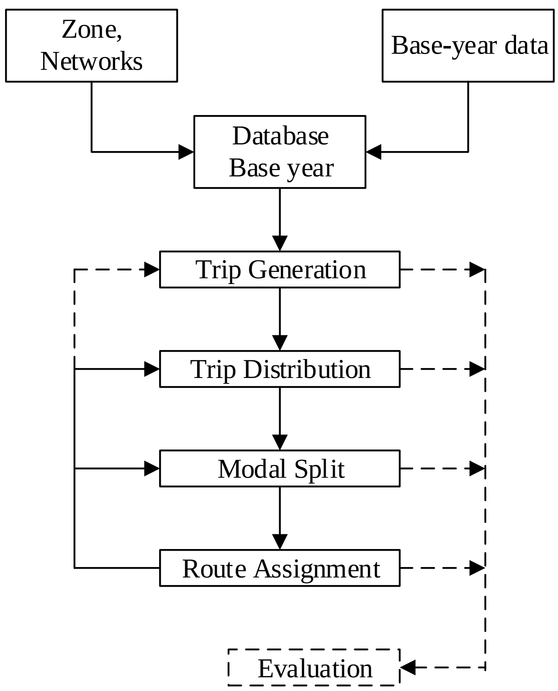


Figure 2-2 The Four-step Model (Ort & Willumsen, 1994)

In terms of the advantages and disadvantages of the four-step model, one of this model's advantage is accuracy, as it can reflect traffic volumes on different routes in the network with different travel modes. Another advantage is that this model can forecast the trend of traffic volumes, which is useful for planners and policy makers to make transport designing decision. For the disadvantage, it is difficult to operate and requires an abundant range of data, most of it is related to traffic zones, transport network, trip factors and socio-economic interaction, some part of data needed are listed above.

Juntunen's road network model

The road network model proposed by Juntunen et al. (2011) consider not only the travel time as an impedance attribute, but also contains information about the CO_2 emissions which are accumulate along the fastest routes for different types of roads. This model can be used to determine optimal driving routes between any pair of locations, and CO_2 emissions associated with each route can be calculated along with the actual route distance. The CO_2 value for a certain destination j was calculated as follows:

$$\boldsymbol{CO_{2_j}} = \sum_i \mathbf{2} * \boldsymbol{c_{ij}} * \boldsymbol{W_i} * \boldsymbol{f} \qquad (4)$$

Where CO_{2_j}: the CO_2 value for a certain destination j;

c_{ij}: the cost distance between origin i and destination j;

W_i: a measure of the mass of location i.

f : CO_2 factor

Here the c_{ij} value is the accumulated CO_2 value for the distance between the origin and the destination and the mass of the origin is the number of households having a car. Similarly, the mass of the origin can be replaced by other elements such as number of households having a motorbike. The 2 value means the return trip.

This kind of road network model is easy to operate, the data needed in this model is easily available, and the use of the road network model enables achievement of much more realistic results than defining routes as Euclidean distances or merely using the physical distance as the impedance. But the focus in the origin and destination in analysing lacks a sufficient consideration of spatial interaction between supply and demand as well as without traffic assignment of different transport modes for estimating CO_2 emissions. Especially, it has the similar pattern of potential accessibility measure, they all discount the job opportunities or CO_2 emissions with the distance.

Selection of Vehicle Emission Estimating Model

The aim of this research for this part is to estimate the vehicle emission, particularly use CO_2 emission, before and after the BRT line is constructed. The choice of CO_2 emission related element and method should basically rely on two aspects. On one hand, it should reflect the CO_2 emission directly and comparable before and after the construction of BRT. On the other hand, the element and method should be suitable for analysing the case of Hanoi based on current available data and should be easy to interpret.

For this research, vehicle type, travel speed, travel distance, emission factor and road types are chosen to estimate the CO_2 emission, these elements are most commonly used in previous research expect for road types, including road types can be more accurate and reliable, as cars running on different road type produce different amount of CO_2 emission. A simplified traditional 4-step model in FlowMap will be used in this case, FlowMap is designed by Utrecht University, it is not build as a transport model , but offers enough functionality perform some elementary transport analysis that are part of a typical transport modelling. For example FlowMap allows to (De, Wel, & Muhammad, 2010): aggregate social-economic data into zonal units by dissolving disaggregated spatial information; to perform shortest path transport network analysis based on different impedance factors (travel time, distance etc); to use the gravity model to model spatial interactions between zones; to perform singly and doubly constrained gravity model analysis; to draw desire lines for spatial interactions; to assign traffic to the network using and all-or-nothing traffic assignment and evaluate traffic flows based on shortest route.

After the traditional 4-step model in FlowMap, traffic flows are assigned to each road segment, then calculate traffic flows into CO_2 emission with CO_2 ratio of different type of road. Additionally, as shown in Figure 2-3 this research intend to aggregate CO_2 emissions into cells to reflect the impact on local level. AB and CD are two road segments, rectangle represent a cell, the number 10 and 20 represent the traffic volume in each road segment. The total emissions of this cell is 10*length of AB * CO_2 ratio (39.6g/km for motorcycle in Hanoi) + 20 length of CD * CO_2 ratio. Finally this research will get a CO_2 emission map for the whole area and along the BRT corridor.

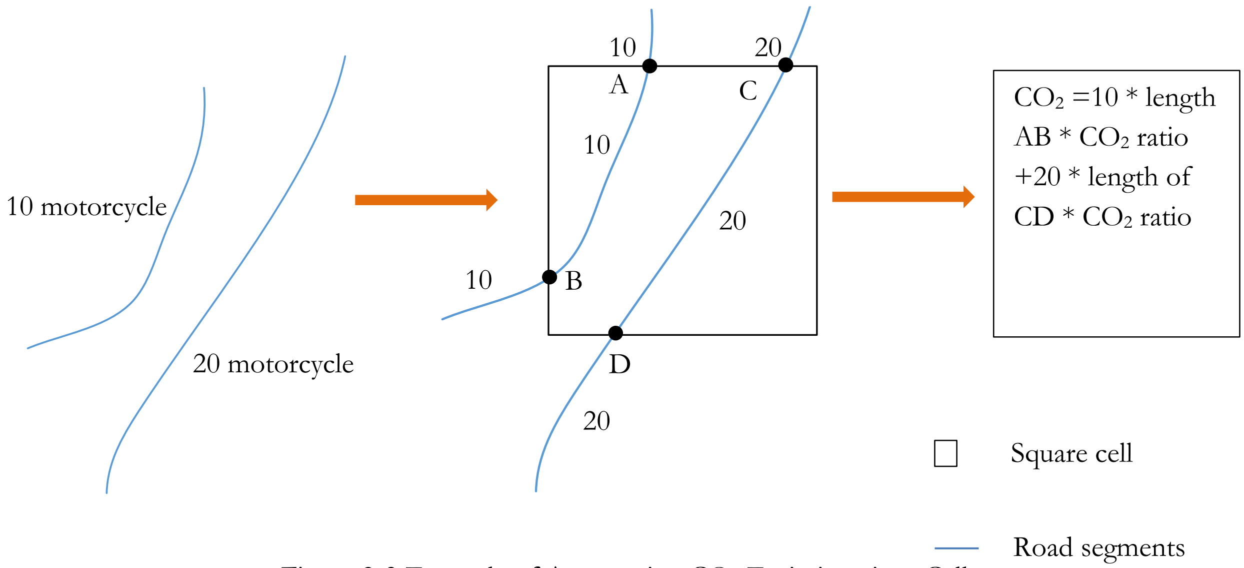


Figure 2-3 Example of Aggregating CO_2 Emissions into Cells

3. STUDY AREA AND DATA

This chapter introduce the condition of Hanoi city, includes geographic location, population, land use, urban transport. Then give a brief introduction of the original data used in this research.

3.1. Overview of Hanoi City

Hanoi, is the capital of Vietnam and second largest city in the country. The city is located in northern region of Vietnam and lies on the right bank of the Red River. Figure 3-1 shows the general location of Hanoi in Vietnam and the Hanoi city area as study area in this research. Hanoi region comprises 16 administrative province with an area of 36000 square kilometres and a total population of about 23 million people. While, Hanoi city in this study has a total population of 3.4 million people (2010) with an area of 400 square kilometres. It is the most important political, economic as well as cultural centre of the country. Moreover, the special geographic location makes Hanoi the most important hub of communications as well as the largest harbour in Northern Vietnam.

Figure 3-1 Geographic Location of Hanoi City

3.2. Population and Area

The study area has approximately 3 billion inhabitants (2010) with an area of 400 square kilometres. As shown in Figure 3-2, the urban area of Hanoi can be classified into three parts, which is core city centre, urban fridge and rural area. In Figure 3-3 we can see the population density in Hanoi, combine Figure 3-2 and Figure 3-3 it is obvious that the high population density concentrate on the core city centre, which means the characteristic of Hanoi is the compactness of its urban area and high population density. The core city centre only covers about 35km², but have a population of over one million, which generate the average population density of around 40 thousand people / km². In dedicated residential areas, the density increases to over 60 thousand people / km². In the urban fringe, the total population density is about 5 thousand people / km², but this masks the uneven population distribution. If only residential areas are considered, the density is over 20 thousand people / km². A similar pattern is also seen in rural areas.

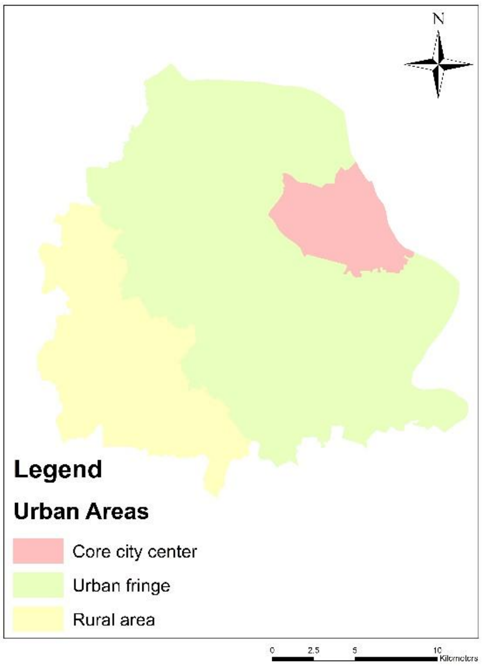


Figure 3-2 Classified City areas of Hanoi

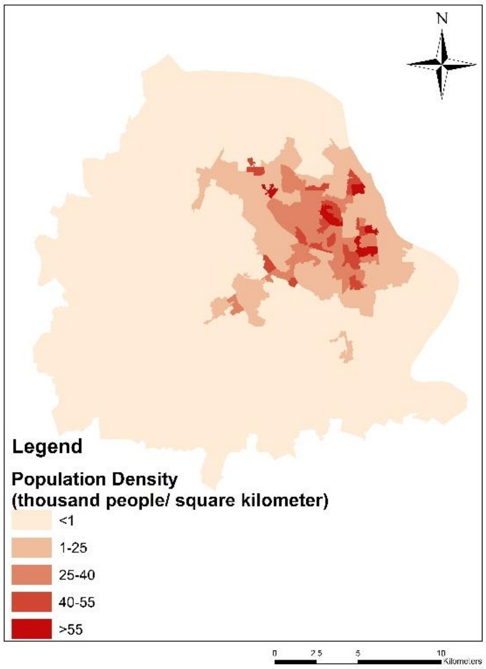


Figure 3-3 Population Density in Hanoi City

3.3. Land Use

In this study area, there is more than 70% is covered by forests, natural sites and agricultural. While only 10% residential, the social-economic function: industry, business and social service account for 3.8%. The land use categories shown in Figure 3-4 is the result of reclassification which explained in section 4.

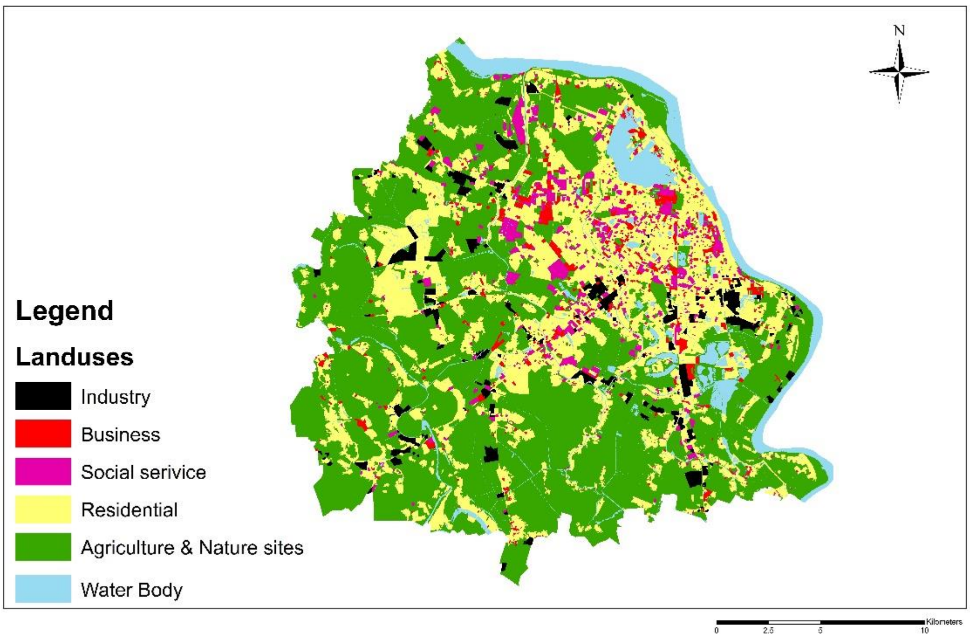


Figure 3-4 Land Use Map of Hanoi City

3.4. Urban Transport

Hanoi has been undergoing rapid urbanization associated with fast economic growth. The trend is expected to continue further. However, an official data showed in Figure 3-5, motorcycle takes up more than half of the mode share which is 59.6%. This has contributed to a phenomenon that Hanoi has the highest percentage of private transportation usage and the lowest percentage of public transportation usage among all Asian capitals. Table 3-1 shows that total trips of different travel mode. Figure 3-6 is the distribution of travel time by transportation mode, which shows the percentage of a certain mode among all the trips by this mode in different time period. Bicycles are the preferred mode for short trips, bus is preferred for longer trips. Trip time by motorcycle, as reported are typically no longer than 40 min.

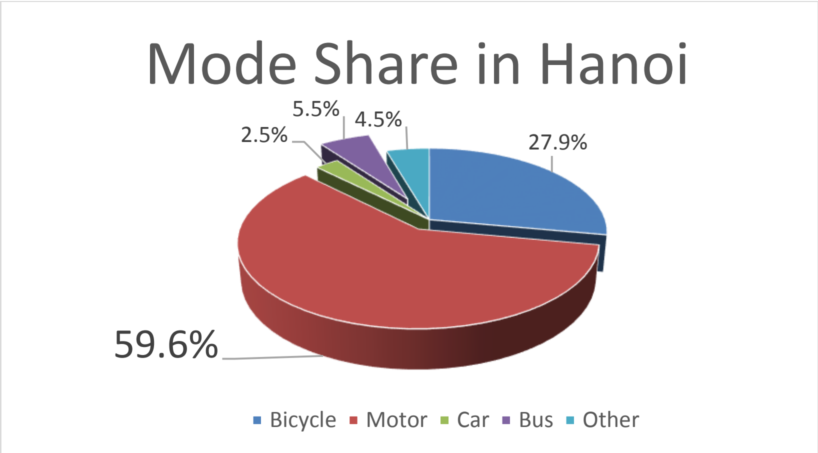


Figure 3-5 Mode Share in Hanoi City (ALMEC Corporation, 2007)

Table 3-1 Trips of Different Travel Mode in Hanoi (ALMEC Corporation, 2007)

Mode	Percentage	Trips(thousand)
Bicycle	27.9%	2231.16
Motor	59.6%	4766.21
Car	2.5%	199.93
Bus	5.5%	439.84
Other	4.5%	359.87
Total	100%	7997

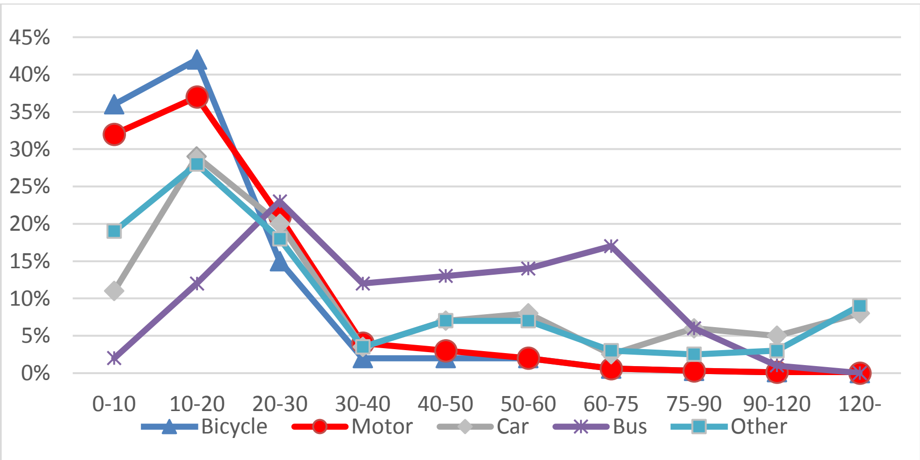


Figure 3-6 Distribution of Travel Time by Transport Mode (ALMEC Corporation, 2007)

Rapid motorcycle-based motorization cause serious environmental problems in Hanoi city (La, Lee, Meuleners, & Van Duong, 2013). Besides, plenty of air pollutants caused by more than two million motorcycle affect the air quality seriously as well as lead to transportation problems such as traffic accidents or traffic congestion (Shimizu, Vu, & Nguyen, 2011). In order to promote public transport system, a BRT system was proposed by Hanoi urban transport development organization which aims to improve the mobility in targeted areas of Hanoi. Two main objectives are expected for this project. First, reduction of public transport system travel time in the city, especially in core centre of Hanoi. The second is to promote the mode shift to more sustainable transport modes in the whole city.

3.5. Data

The data has been prepared by Mr. Nguyen Ngoc Quang, PHD candidate at the Department of Urban and Regional Planning and Geo-information in ITC. The original data which are available are displayed in the Table 3-2 below, which include: spatial data and non-spatial data. Land use, Population per ward and commune, road network, bus network and BRT line are spatial data. The non-spatial data is job related data. It includes the number of jobs in different sectors and subsectors in total Hanoi.

Table 3-2 Original Data in Hanoi City

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 and commune	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.	
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		

Three travel modes are explored, Motorcycle for private transport, Bus and BRT for public transport. Some related parameters are listed in Table 3-3. The average speed of walking, bus, BRT and the corresponding waiting time and get off time are obtained from Hanoi Master Plan in 2007 (ALMEC , 2007) and the Hanoi Urban Transport Development Project in World Bank Project (The World Bank, 2007). The average speed of motorcycle is obtained from Ha et al., (2011). The CO_2 factor for motorcycle and bus is from Lee, (2008). 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.

Table 3-3 Transport Parameters in Hanoi City

Mode	Road Attribute	Speed (km/h)	CO_2 factor [2] (g/km)	Time for waiting	Time to get off	Data Source
Motorcycle	Expressway	45	39.6	N/A	N/A	(Ha et al., 2011) (Lee, 2008)
	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	(ALMEC , 2007) (The world bank, 2007)
	Urban Fringe	20				
	Rural	25				
BRT	N/A	28	--	3 min	20 seconds	(The world bank, 2007)
Walking	N/A	3.5	N/A	N/A	N/A	(ALMEC , 2007)

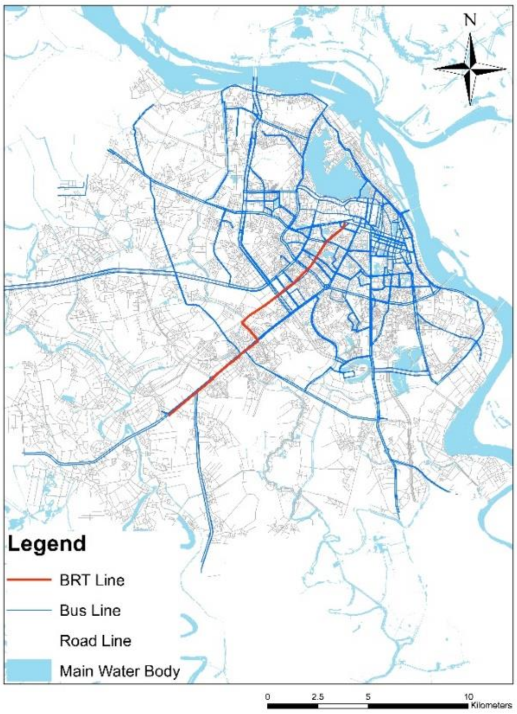


Figure 3-7 Road Networks and Public Transport System in Hanoi City

The transport system of the Hanoi city which will be applied in this research can be divided into parts, as shown in Figure 3-7: Road line represent the basic roads in Hanoi city; Bus line stand for the bus system in Hanoi; BRT line represents the new proposed BRT line in Hanoi city.

[2] (1)An emissions factor is a measure of the rate that pollutants are emitted relative to units of activity and vary with vehicle technology, vehicle maintenance and tuning, driver behaviour, temperature, etc. An emission factor can be measured in units of grams emitted per kilometre travelled by the vehicle (g/km).
(2) The CO_2 emission factor by motorcycle used in this study is measured at the Laboratory of Internal Combustion En-gine, Hanoi University of Technology.

4. METHODOLOGY

This chapter describes how the MAG and MEG indicator are implement. It includes three main sections. The first section is origin and destination data preparation. The second section is the procedure of computing the indicator for job accessibility. The last section is the procedure of computing the indicator for CO_2 emissions.

4.1. Origin and Destination Data Preparation

In order to analyse the job accessibility and CO_2 emission in the study area of urban Hanoi, we need to know workers in every origin go to which job location based on the shortest route. First is to identify the spatial distribution of job locations and residential locations. The tool used to compute shortest route in ArcGIS needs the origin and destination represent with points, thus the spatial distribution of residential locations (origin) and job locations (destination) which represented with points in Hanoi needs to be identified, as well as population and job numbers in each location.

The original data listed in Table 3-2 lack of the spatial distribution of residential locations and job locations represent with points, so identifying the residential locations and job locations as well as estimating the population in each location is needed. The total number of land use polygons are 24198, the average area is 0.051 km^2, while the total number of commune polygons are 189, and the average area is 2.33 km^2. The number of locations are too many for job location to do Network Analyst and difficult to represent with points. For residential area the traditional unit is too large, it's not accurate to represent it with the central point. Cheng & Bertolini (2013) used resolution in 500*500m cell as a basic analysis unit to aggregate the employment data and disaggregate inhabitant data in the Amsterdam region. The traditional unit is administrative district and neighbourhood with an average size of 14.4 km^2 and 3.2 km^2, and they use a lower spatial units to avoid low levels of accuracy. Comparing the average size of the origin and destination locations of this study with Cheng & Bertolini (2013) it is proper to use the 500*500 meters resolution cell for the whole area in Hanoi to generate the jobs locations and residential locations and represent it with the centroid of the cell.

Reclassification of Job Types and Land Use

In job data the original governmental official employment data has four main types: Industry, Government Office, Business Enterprise and Social Services. The original job data are reclassified into 3 job types which are easy to interpret and operate in the following step. The 3 reclassified job types are: (1) Industry, (2) Business and (3) Other Social Service. There are total number of 1,708,070 jobs in the study area, the details of the reclassification rules are shown in Appendix A. This kind of reclassification aims to assign the number of jobs in to related land use location.

After jobs are reclassified into 3 types, in order to split job numbers into job locations, corresponding job locations in land use data should be selected out and reclassified into the same 3 types to match the job types that have been reclassified in job data. The detail classification rules of land use are demonstrated in Appendix B. The classification rule is based on the property of each land use, like Market is classified in Business.

Identify Job locations and Quantify Number of Jobs

The flowchart of how jobs were assigned in the study area is shown in the Figure 4-2. First, reclassify job into three types. Second, using 500*500 fishnet to aggregate job numbers. Third, represent job numbers in each cell with point.

In data level For 1, 2 and 3 are some calculation in the table of certain type of data, the formula for 1 is as follows:

$$D_J^n = \frac{P_n}{A_n} \quad (5)$$

Where:

D_J^n: job density (number of jobs per square meter) of certain job type;
P_n: total number of jobs in certain job type;
A_n: total land use areas of certain job type;
n: job type; industry, business and social service.

After the calculation each land use location could be assigned a job type and a corresponding job density. 2 is calculate areas of certain job type in each square. In 3 use the job density of certain job type in 1 multiply the areas of certain job type in each square in 2, then the population number of certain job type in each square can be worked out. Finally, after summary the total job numbers in each cell and link it with spatial locations, there are total 1024 job locations represented by points at a resolution of 500*500m. And the final job distribution shows in Figure 4-1 below.

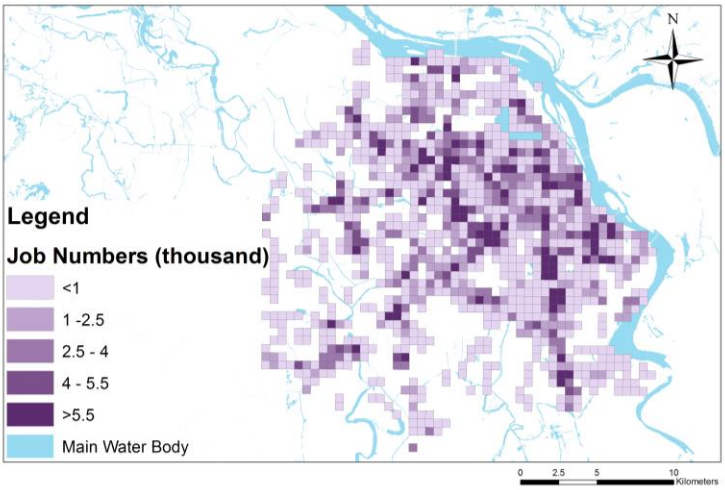


Figure 4-1 Final Job Location Distribution in Hanoi City

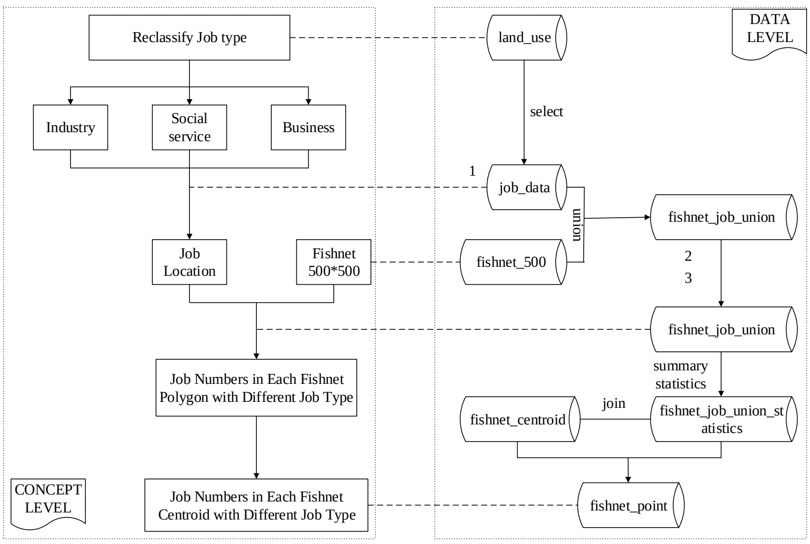


Figure 4-2 Flow Chart of Procedure for Preparing Job Location

Identify Residential Locations and Quantify Number of Population

For the residential areas, the population data for each community is available in the study area, but the spatial distribution of residential location is not identified. Therefore the land use data is applied to determine the spatial location of residential areas. Figure 4-4 shows the procedure for preparing residential location. There are two types of residential areas: urban area and rural area. First, assign population in each commune to the residential area. Second, using 500*500m fishnet to aggregate population. Third, represent population in each cell with point.

In data level, after union residential areas with commune, by using the result of study by Zhang, (2014) population distribution For the communities covered by both "urban areas" and "village areas " is 80% and 20%, respectively. Then in each community, sum up shape areas of all the "urban areas" or "rural areas" and use the follow formulas in 4 to calculate the population density in each residential area:

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

$$Population_{density\ (people/m^2)} = \frac{Total\ number\ of\ population\ in\ that\ community\ (people)}{Total\ shape\ areas\ of\ urban\ (rural)\ areas(m^2)} \quad (6)$$

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

$$Population_{urban} = Population_{community} * 80\% \quad (7)$$

$$Population_{urban} = Population_{community} * 20\% \quad (8)$$

$$Population_{density\ (people/m^2)} = \frac{Total\ number\ of\ population\ in\ urban\ (rural) areas\ (people)}{Total\ shape\ areas\ of\ urban\ (rural)\ areas(m^2)} \quad (9)$$

500*500 resolution fishnet is created to aggregate these residential areas. The next step is in (9) is using the population density and shape area to calculate the total population. Last step, sum up the total population in each fishnet cell and use the centroid of the cells to represent residential locations. The final number of residential locations after disaggregation is 1195. The total number of people in residential location is 3,105,581.The final distributions of residential locations are shown in Figure 4-3 below.

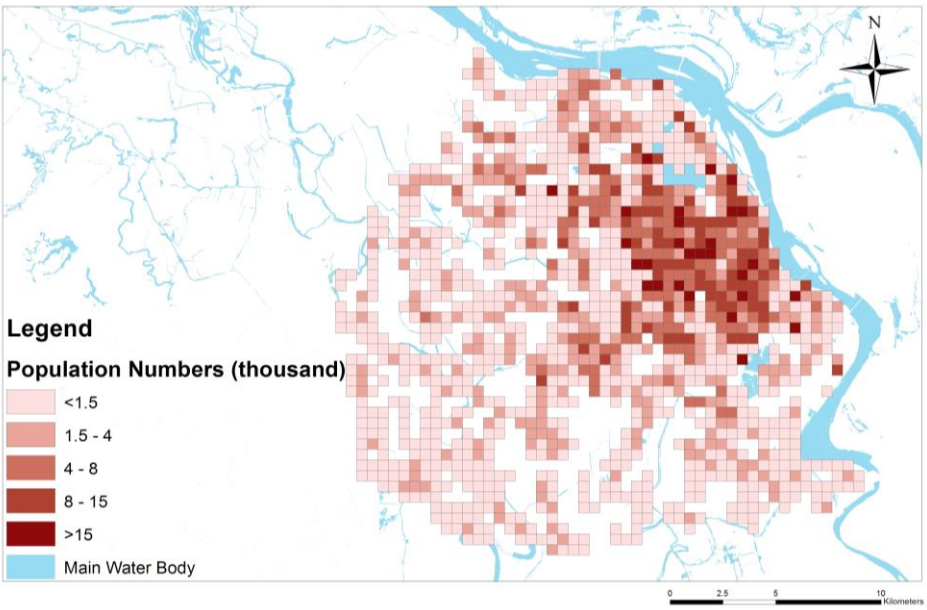


Figure 4-3 Final Residential Location Distribution in Hanoi City

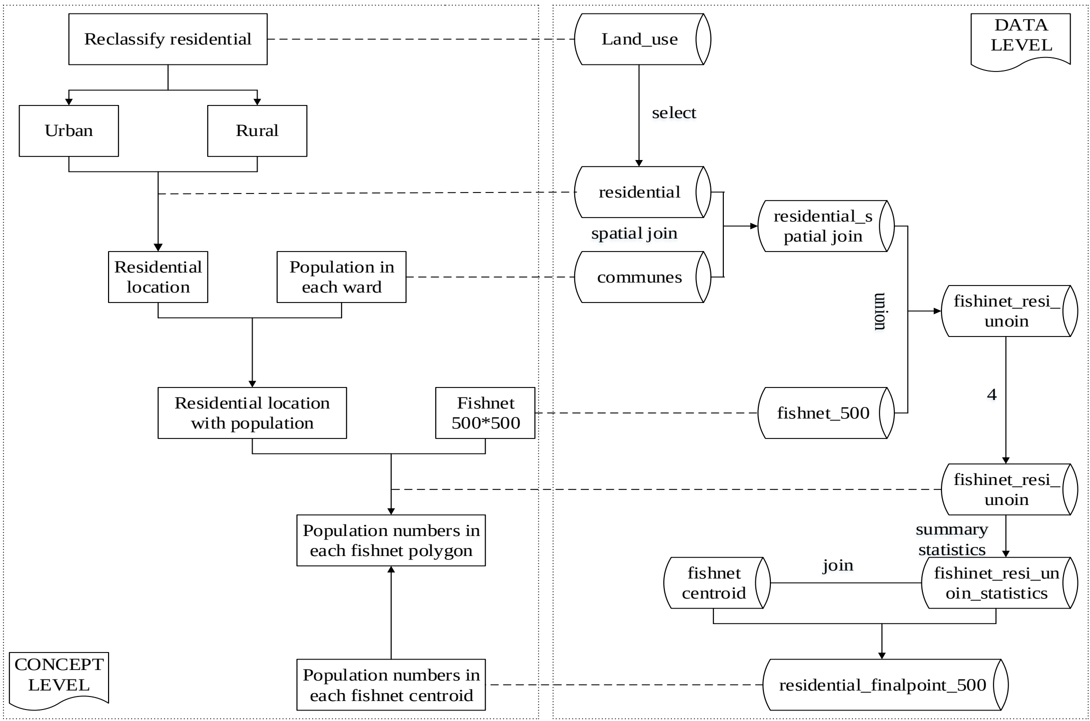


Figure 4-4 Flow chart of Procedure for Preparing Residential Location

4.2. Computing indicators for Job Accessibility

Potential Accessibility Measure

The potential accessibility measure is based on there are spatial interaction between each residential location and job location. This interaction is related with travel time (distance) from each residential location to each job location. The job opportunities will be discounted by distance decay. The formula below will be applied in this research (Geurs & van Wee, 2004):

$$A_i = \sum_{j=1}^{n} D_j f(c_{ij}) \quad (10)$$

$$f(c_{ij}) = e^{-\beta c_{ij}} \quad (11)$$

Where A_i: accessibility value from residential location i;

D_j: the number of job in job location j;

c_{ij}: travel time from residential location i to job location j (in minutes);

f (c_{ij}): distance decay effect from residential location i to job location j;

β: the decay parameter whose range is from 0 to 1.

n: total number of job locations

Decay Function

The time decay function is proposed by Ha et al., (2011). As shown in Figure 4-5 they use 0.5 as β for Hanoi to represent the average travel time, for example when travel time is 20 minutes from worker location to job location, 20% of the workers are willing to go there.

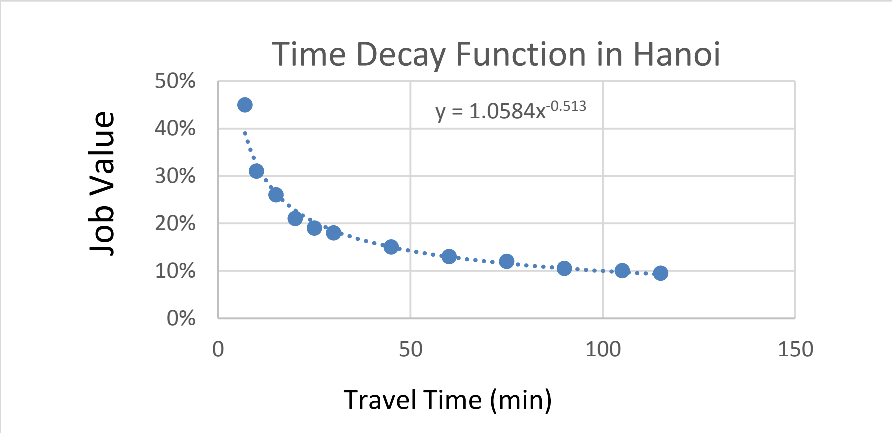


Figure 4-5 Impedance Function Used in This Study (Ha et al., 2011)

Methodology for MAG

Modal Accessibility Gap is measured as follow:

$$\mathbf{MAG} = \frac{A^T - A^P}{A^T + A^P} \quad (12)$$

Where A^T: accessibility value of transit (Bus and BRT);

A^P: accessibility value of private transport (Motorcycle);

T : Transit (Bus and BRT);

P : Private transport (Motorcycle).

The value of MAG varies between -1 and +1. The higher this value the better the accessibility to jobs by public transport is. This research focus on the accessibility difference between different travel modes, especially motorcycle. The BRT line occupies a relatively small part of Hanoi area, thereby the impact of the BRT or the people willing to shift from motorcycle will most concentrate along the BRT corridor.

Selection of BRT Corridor

The most common standard measure of walking distance to transit stops and stations has been 700 meters (Gutiérrez, J and García-Palomares, 2008; Daniels & Mulley, 2011). The study of Gutiérrez, J and García-Palomares, (2008) support evidence that people will walk from 400 m to around 1200m to access public transport in USA, once they have decided to walk. While Daniels and Mulley, (2011) found the mean walking distance to bus service at 856 meter in Sydney. After that Grimsrud and Wasfi, (2014) investigated that the walking distance to bus transit service is around 924 meters from home-based trip origins in Montreal, Canada. On the basis of the above we may carefully concluded that, in a reasonably well served urban area, passenger should be able to catch a bus within around 800 -900 meters from their home or work place. This study will use a 875 m/15 min walking service area, as shown in Figure 4-6 along BRT as BRT corridor (from BRT station along the road network create 15min service area via Network Analysis). People willing to shift from motorcycle to BRT will mostly be from within this area.

In order to use MAG to evaluate the effect of BRT. Transport scenarios are introduced in Table 4-1. By comparing MAG with and without BRT the effect of BRT can be reflected in both Hanoi city and BRT corridor. The introduction of congestion scenario in BRT corridor is a test of BRT influence on motorcycle. BRT has a characteristics of exclusive line that means when congestion occurs, the speed of motorcycle will decrease, but speed of BRT and Bus won't, therefore there will be more people can travel faster by BRT than by motorcycle. Lee (2008) proposed that the traffic speed will decrease to 65% when traffic congestion occurs in Hanoi. So a congestion factor 0.65 is applied to estimate congestion level in Hanoi. Related parameter in congestion scenario is shown in Table 4-2:

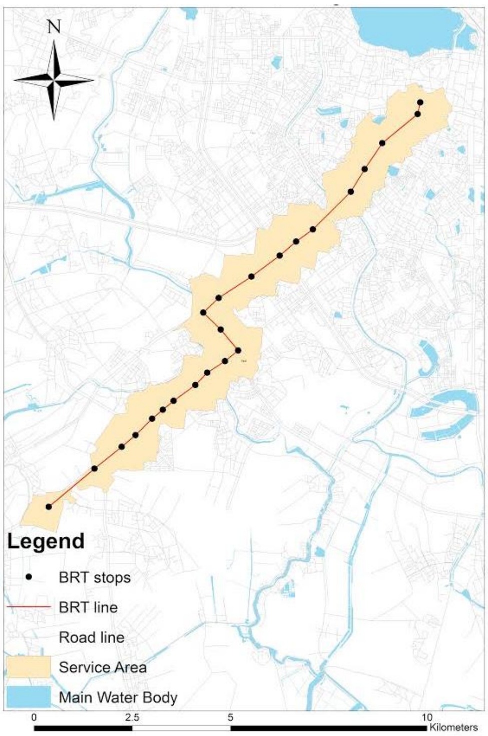


Figure 4-6 15 min walking BRT Corridor

Table 4-1 Transport Scenarios for Analysing MAG

Scenarios	logogram	Explanation
Motorcycle _ Bus	M_B	MAG between motorcycle and Bus
Motorcycle_ Bus[3] BRT	M_BB	MAG between motorcycle and a combine of Bus & BRT
Bus_ Bus BRT	BB_ B (Hanoi City to reflect the influence area of BRT)	MAG between Bus and Bus & BRT
Congestion	(MC_B) and (MC_BB) (BRT corridor)	The first two scenarios with motorcycle has congestion

Table 4-2 Traffic Property of Congestion Scenario

Mode	Road Attribute	Average Speed before congestion (km/h)	Average Speed after congestion (km/h)
Motorcycle	Expressway	42	27
	National road	37	24
	Primary road Province road	32	21
	District road, Local main street Secondary road	27	18

[3] The combination of Bus & BRT using Multi-modal Road Networks in ArcGIS software. In this function ArcGIS will automatically compare all the alternative routes of all possible combination of travel modes such as travel by Bus; BRT; Bus and Shift to BRT; BRT and Shift to Bus and then select out the route which takes the shortest time.

MAG will be applied in the whole area and BRT corridor, as the whole area in Hanoi is too big to make residential location point and job location point controlled in 100*100 resolution (if origin points and destination points are too many, about 10000 points). In order to release the burden of computer, a sub-area based on decay function mentioned in section 4.2 is selected. From the decay function we know that 80% people travel from their home to employment location, the travel time should be 20 minutes. If people travel by motorcycle, average speed for motorcycle is 22km/h, the sub-area is selected at 7 km area from BRT station. Then, 250*250 resolution cell's centroid will be used to represent the residential location and destination location for computing job accessibility in BRT corridor.

4.3. Computing Indicators for CO_2 Emission

Transportation Modelling

The 4-step Model is implemented in FlowMap software. It enhances development of theoretical knowledge about the four-step transport modelling as well as simplified the complicated procedure of calculating. This research attempts to study the CO_2 emission estimation on motorcycle. The step for modelling traffic volume follows the traditional 4-step model.

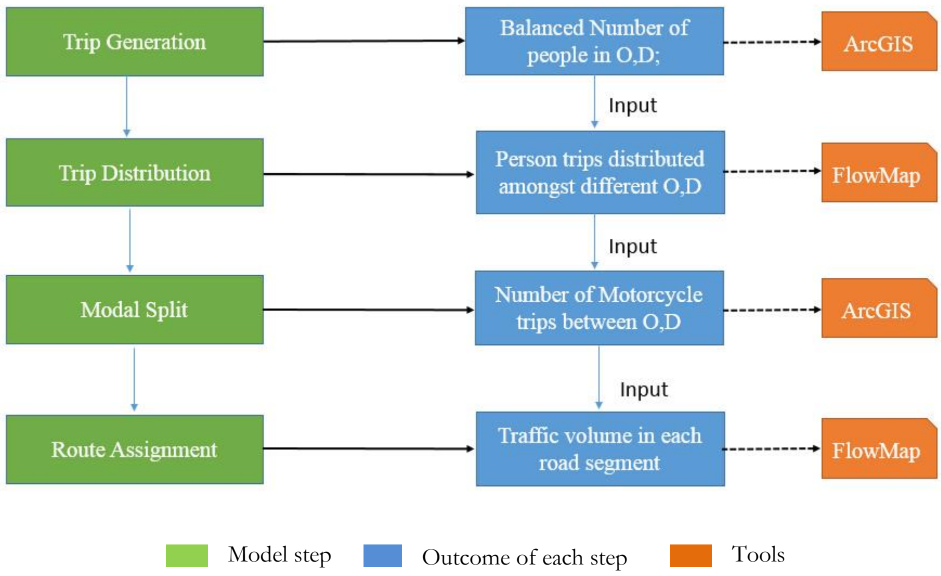


Figure 4-7 4-step Transportation Model in This Research

Trip Generation

Trip generation can be separated into two parts: trip production and trip attraction. (1)Trip production: the population in residential locations stand for people of trip production. (2) Trip attraction, the number of jobs in job locations stand for people of trip attraction. It assumes that the population in the working age (55% of the total population (ALMEC Corporation, 2007) is a good proxy (independent variable) for trip productions. Since the trips from certain origin must end somewhere, production and attraction numbers should be equal. Given that the input data have different sources, they are not equal, and balancing between production and attraction is needed. The method of balancing based on the following formulas (Ort & Willumsen, 1994):

$$f = \frac{\sum_{i=1}^{i} O_i}{\sum_{j=1}^{J} D_j} \tag{13}$$

$$\widetilde{D}_j = f D_j \tag{14}$$

Where: O_i is the total number of people in the residential (production) locations;
D_i is the total number of people in the job (attraction) locations;
$\widetilde{D}_j$ is the refined total number of people in the job (attraction) locations;
f is balance factor.

After balancing there are 1,708,070 people in total for residential locations and job locations. According to the study (ALMEC Corporation, 2007), every people generate 2 trips in average per day for work. Thus, there are 1708070 *2=3416140 trips in total between each origin and destination.

Trip Distribution

This step with a purpose of distributing trips to particular job location. A doubly-constrained gravity model is applied. This step matches residential locations and job locations to develop an origin and destination trip table, the matrix reflects the number of trips going from each residential location to each job location. A distance decay function is used in the doubly-constrained gravity model. It reflects the effect of distance on spatial interactions.

Before operating the doubly-constrained gravity model, a distance table should be generate from each residential location to each job location using the network. A doubly constrained gravity model estimates the most probable distribution of flows in a matrix of origins and destinations. Jong & Vaart, (2013) applied a doubly constrained gravity model to model the spatial interaction of transport. The formulas is as following:

$$T_{ij}=A_i.B_j.O_i.D_j\boldsymbol{f}(C_{ij},\beta) \quad (15)$$

$$A_i=1/\ (\textstyle\sum_j B_j\ .D_j.\ \boldsymbol{f}(C_{ij},\beta)) \quad (16)$$

$$B_i=1/\ (\textstyle\sum_i B_j\ .D_j.\ \boldsymbol{f}(C_{ij},\beta)) \quad (17)$$

$$\boldsymbol{f}(C_{ij},\beta)=\exp\ (-\beta.\ C_{ij}) \quad (18)$$

Where:
T_{ij}= the estimated number of trips between residential location i and job location j;
A_i= the balancing factor for residential location i;
B_i= the balancing factor for job location j;
O_i= the constraint value for residential location i;
D_j= the constraint value for job location j;
β = the distance decay parameter, it has been explained in 4.2.;
C_{ij}= the distance between residential location i and job location j.

The balancing factors A_i , B_i aims at making sure that the total estimated outflows per residential location equals the known residential location total and the total of the estimated inflows per job location equals the known job location total. Formula (15) calculates the actual trips in the origin destination matrix. Formula (16) equals the total number of trips from residential locations in the matrix to O_i. Formula (17) equals the total number of trips to the job locations in the matrix to the number D_j . The value of the distance decay parameter used in this research has been explained in section 4.2.

- **Calibration of model results**

The model can be calibrated on the Mean Trip Length (MTL). It means that the model estimates the interaction matrix based on the residential location and job location totals. The estimated MTL is then calculated using the following formula:

$$\text{MTL}=(\textstyle\sum_i\sum_j T_{ij.}\ C_{ij})\ /\ (\sum_i\sum_j T_{ij}) \quad (19)$$

Where:

T_{ij} = the estimated number of trips between residential location i and job location j;
C_{ij} = the distance between residential location i and job location j.
If the distance calculated with the starting value of the distance decay parameter β different from the defined MTL, the mentioned calculation steps are all run again, until the estimated MTL equals the defined MTL. In this study the mean trip length by motorcycle set 20min from the survey result by ALMEC Corporation, (2007).

Modal split

In this stage, the mode use will be predicted. As in Hanoi most CO_2 emissions come from motorcycle, thus this research only consider the motorcycle share. With the existing data explained in Figure 3-5 mode share and trip of different travel modes in Table 3-1, the mode share of different travel mode in different time period can be calculated, the result is shown in Figure 4-8.

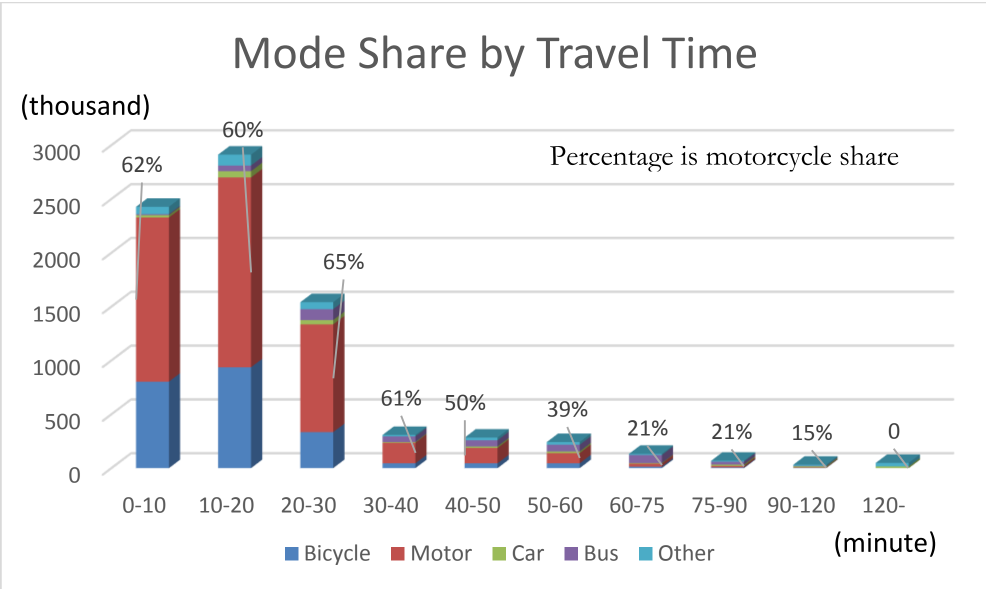


Figure 4-8 Mode Share by Travel Time

Trip assignment

The last step in the 4-step transport model requires the trips by each mode are assigned to their corresponding networks. Traffic assignment mainly performs the route choice on the network for all trips between each residential location and job location pair. And 'Flow Assignment to Network' analysis in FlowMap to assign traffic flows on the road network based on all-or-nothing method.

CO_2 calculation

After the 4-steps, the traffic volume assigned to each road segment. In order to estimate CO_2 emission, as shown in Figure 4-9 the road lines are intersected with cells, after intersection, in each cell the length of the segment is known, traffic volume passed the segment in each cell has been calculated in previous step, therefore CO_2 = the length of the segment* traffic volume passed the segment* CO_2 factor (39.6g/km), after aggregating CO_2 into different cells (500*500 in whole Hanoi, 100*100 in BRT corridor), we can know the magnitude of CO_2 emission for each individual cell.

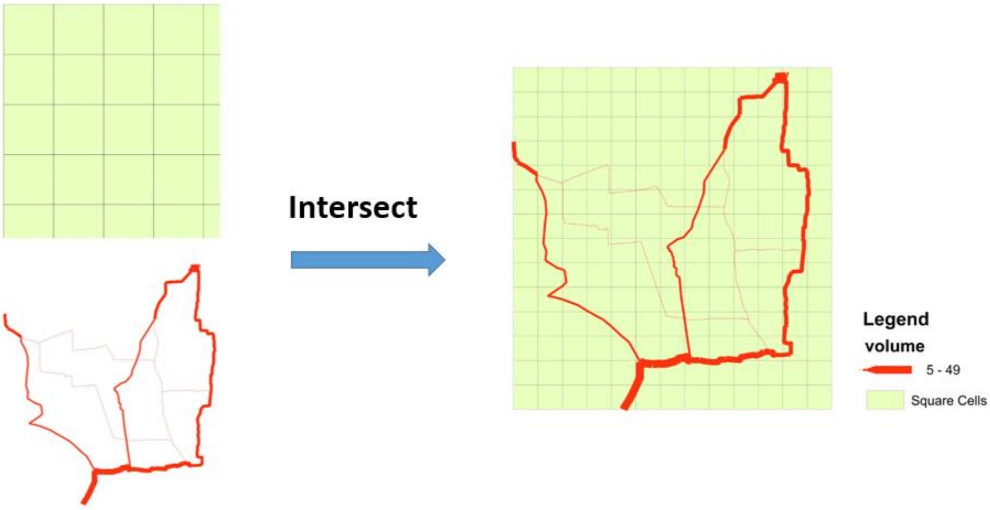


Figure 4-9 Example for Intersecting Traffic Volume with Cells

Spatially distribute mode shift

In order to spatially distribute the mode shift, secondary data are used for estimating mode shift. A result of person trip survey for modelling choice in Hanoi are used (1200 samples) (Shimizu et al., 2011). As shown in Figure 4-10, it reflect the change of choice probability of bus by time, from this we can know that when the time difference (bus-motorcycle) increases the possibility will decrease. The red survey curve use the survey data comes from the study by Shimizu et al., (2011) without the decay function. By using the data the derived curve and related function can be produced. CO_2 mainly comes from motorcycle, for evaluating the impact of BRT it focus on the mode shift from motorcycle to BRT. By applying this survey data, assumes that people will have same willing to take BRT.

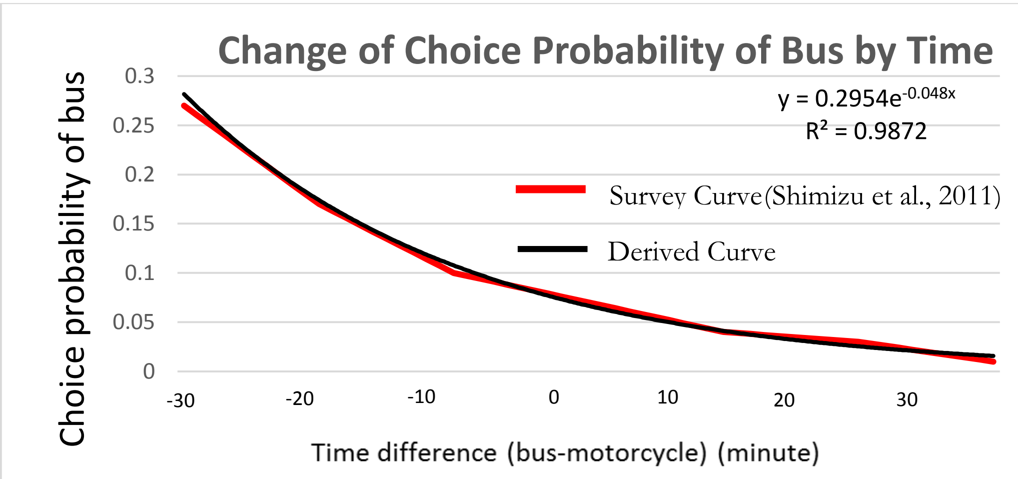


Figure 4-10 Change of Choice Probability of Bus by Time Difference

Methodology for MEG

The MEG is measured as follow:

$$\mathbf{MEG} = \frac{E^B - E^A}{E^B + E^A} \tag{20}$$

Where E^B: motorcycle emission (CO_2 in this study) in base scenario (without BRT in transport system);

E^P: motorcycle emission (CO_2 in this study) in after scenario (with BRT / with BRT and congestion in transport system);

B : base scenario (without BRT in transport system);

A : after scenario (with BRT / with BRT and congestion in transport system).

This MEG is proposed based on the principle of MAG. The value of MEG varies between -1 and +1 to reflect the emission change level between different transport scenarios. When MEG is above 0, the higher this value the emission decreases when comparing the base scenario against the after scenario. When MEG below 0, the higher this value means less emission increase compare base scenario and after scenario. If MEG equals 0, that reflect there is no emission decrease and increase between different transport scenarios. This study plans to use this indicator to evaluate the impact of BRT.

Transport Scenarios

Three scenarios will be used in motorcycle CO_2 estimation in the corridor with 100*100 cells to visualise the local emission decrease areas, as shown in Table 4-3. The scenario 1 estimates motorcycle CO_2 emissions without BRT, the scenario 2 is some proportion of motorcycle users shift to BRT, the amount of motorcycle CO_2 emissions. The scenario 3 is in the hypothetical situation of congestion, the introduction of congestion scenario is a test of BRT influence in the corridor. Where motorcycle travel speed decreases, see Table 4-2.

Table 4-3 Scenarios for Estimating CO_2 Emissions

Scenarios	Explanation
Scenario 1	Estimating CO_2 emissions of motorcycle with no people shift to BRT.
Scenario 1	Estimating CO_2 emissions of motorcycle with some people shift to.
Scenario 2	Estimating CO_2 emissions of motorcycle with some people shift to BRT in the situation of motorcycle congestion.

5. RESULTS AND ANALYSIS

In this chapter, results of the comparative indicator of job accessibility and CO_2 emission are demonstrated. First, it discusses the indicators for job accessibility in both the whole Hanoi city and BRT corridor at global level and local level[4]. Second, the result of potential CO_2 emission saving is reflected, and the comparative indicator MEG is discussed for the corridor area at global level and local level.

5.1. Indicator for Job Accessibility

Potential Job Accessibility

Following the methodology described in Chapter 4, job accessibility for different travel modes is computed using a potential job accessibility measure. For each travel mode, some key statistics and maps are shown and discussed as follows:

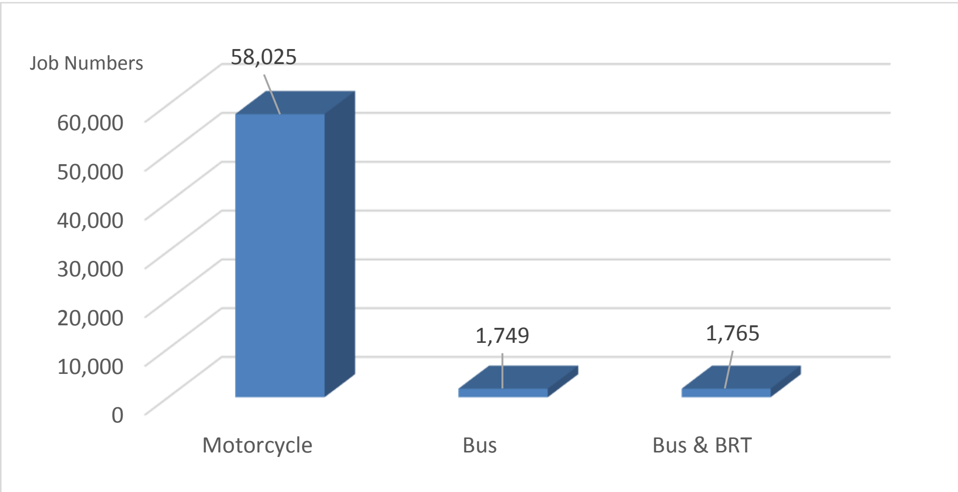


Figure 5-1 Mean value of Potential Job Accessibility by Different Travel Modes

Job accessibility of M is much higher than that of B and BB[5]. The mean value of job accessibility M, B, and BB are 58025, 1749 and 1765 respectively (Fig. 5-1). Besides, BB is only 16 jobs higher than B which means for whole Hanoi city the contribution of BRT is very small in promoting job accessibility.

High job accessibility concentrated on the city centre and gradually decline from the city centre to the outer areas by all the three transport modes (fig. 5-2). This is mainly because of the concentration of transport networks and high population density and job density in the city core. Transport system has influence on the job accessibility, in (b) and (c) the high job opportunities locations are all next to bus lines and the BRT line. However, as illustrated in Figure 5-1, job accessibility of M is overwhelming higher than B and BB. It is difficult to see the difference of the job accessibility by comparing these three modes directly. So, the next part is analysing the accessibility difference between different transport modes.

[4] Global level: using statistics numbers to represent overall situation.
Local level: using maps to show the situation of different locations.
[5] M: Motorcycle; B: Bus; BB: Bus & BRT

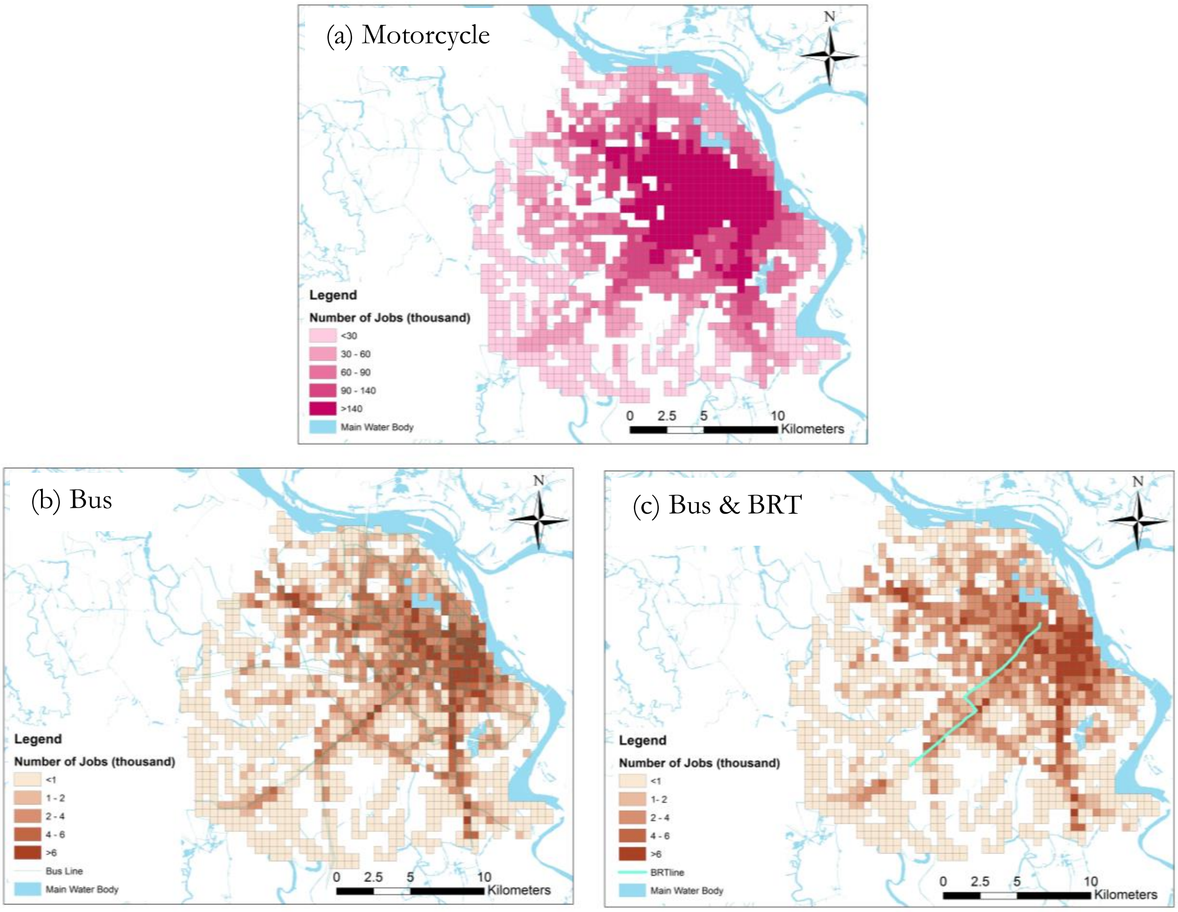


Figure 5-2 Potential Job Accessibility by Different Travel Modes[6]

Modal Accessibility Gap

This section analyses the accessibility difference between different transport modes to see the impact of the BRT line for the whole Hanoi.

Majority of people have good access to their job opportunities by motorcycle, but not public transport. It can be reflected by the Maximum MAG value between Bus and Motorcycle (B_M) and MAG value between Bus & BRT and Motorcycle (BB_M) are below 0 (Table 5-1). The MAG mean value of BB_M (-0.9600) is higher than of B_M (-0.9603) which shows BRT promotes some job accessibility. As the job accessibility difference is too small to reflect the change visually, we don't analyse MAG of B_M and BB_M in local level (Appendix D).

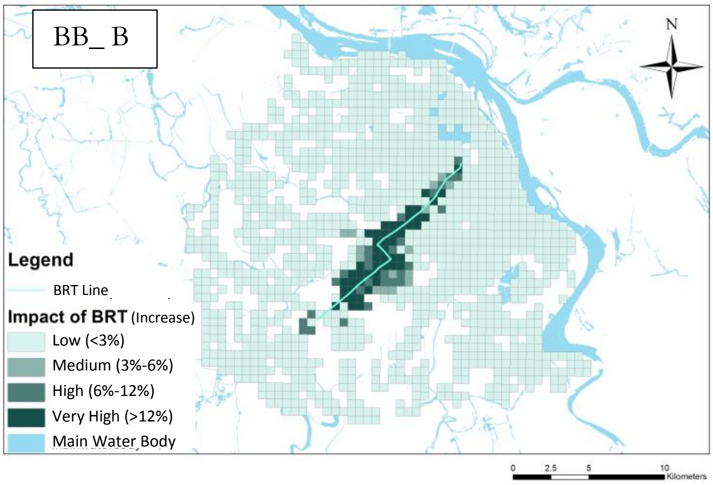
In order to reflect BRT impact areas and impact level, a MAG between Bus & BRT and Bus (BB_B), and between B_M and BB_M are calculated. The minimum value is 0 (Table 5-1) which means BRT contributes to the improvement of job opportunities. But the promoting of job accessibility in public transport system is very slight, the most benefits residential locations are 52 out of 1195 along the BRT line (>6% accessibility increase) and 27 out of 1195 residential locations (>3% accessibility increase) when public transport compete with motorcycle (Fig.5-3). One reason is that the motorcycle's utilization is overwhelming high in

[6] Same colour of maps represent same scale. In Figure 5-2 the range of M is much broader than B and BB, it has different scale with B and BB.
The classification used for all the maps is 'nature breaks', the reason see Appendix C.

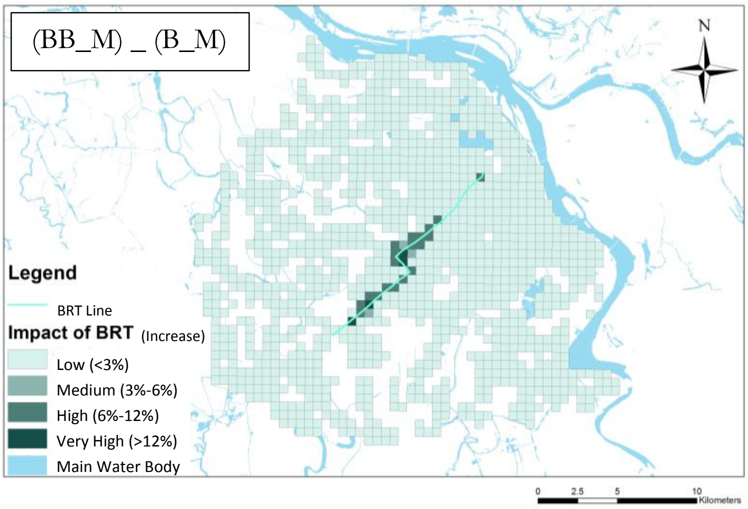
Hanoi city. Another reason is that public transport can only be accessed at bus or BRT stations. From that perspective, motorcycle is more convenient than public transport, as it can be used directly from people's home to their destination.

Table 5-1 Statistical Description of Job Accessibility Gap between Different Travel Modes

MAG Scenarios [7]	Minimum (MAG)	Maximum (MAG)	Mean (MAG)
B_M	-0.9999	-0.6568	-0.9603
BB_M	-0.9999	-0.6567	-0.9600
BB_ B	0	0.5832	0.0045
(BB_M) _(B_M)	0	0.0226	0.0004



(a)



(b)

Figure 5-3 Impact of BRT Based on Job Accessibility Difference

[7] B_M: MAG between Bus and Motorcycle (a); BB_M: MAG between Bus & BRT and Motorcycle (b); BB_ B: MAG between Bus & BRT and Bus; (BB_M) _(B_M): MAG between (b) and (a)

Potential Accessibility Measure in BRT Corridor

This section analyses the result of potential job accessibility within the BRT corridor. M and MC still have advantage in potential job accessibility over B and BB, which is reflected in the mean value shown in Table 5-2 and Figure 5-4. When comparing the scenario M and MC, once congestion occurs, the speed of the motorcycle will decrease obviously. This leads to a significantly reduce in the job opportunities accessed by motorcycle, which is 19.4%. Meanwhile, by comparing B and BB, the BRT line promotes 4.2% of the job opportunities in the corridor of Hanoi city.

Table 5-2 Statistical Description of Potential Job accessibility of Different Travel Modes

Transport Type	Mean (Job Numbers)	Increase/Decrease
Motorcycle(M)	48,378	-19.4% (MC compare with M)
Motorcycle in Congestion(MC)	38,992	
Bus(B)	20,678	4.2% (BB compare with B)
Bus & BRT(BB)	21,573	

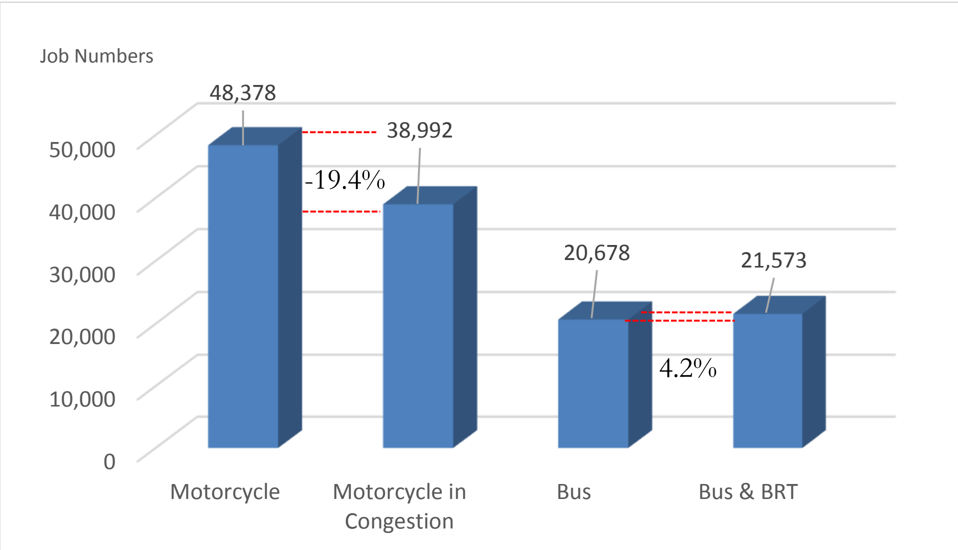
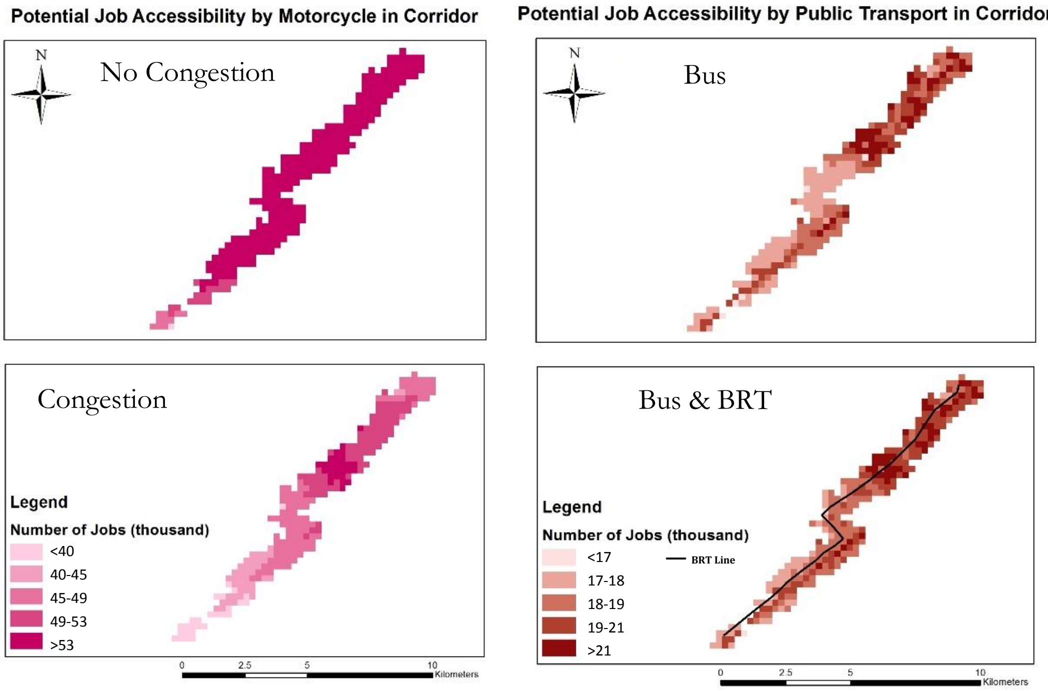


Figure 5-4 Mean Value of Potential Job accessibility by Different Travel Modes in BRT Corridor

The maps in Figure 5-5 present the spatial distribution of potential job accessibility by M, MC, B, and BB in the BRT corridor in Hanoi. As can be seen from (a), great changes (decrease of job accessibility by motorcycle) have taken place in the most areas of the corridor due to the traffic congestion. Especially close to the areas of the city core where is covered by more small roads and more job locations than the outer area. Meanwhile, in (b) job opportunities concentrate on where there is bus line or BRT line, which means the public transport network can improve the accessible of job opportunities. When comparing the job accessibility of B and BB, BB shows higher job accessibility in almost all areas in the corridor. The BRT line made people live in the corridor area can reach more job opportunities.



(a) (b)

Figure 5-5 Potential Job Accessibility by Different Travel Mode in BRT Corridor

Modal Accessibility Gap in BRT Corridor

This section analyse MAG between different transport modes in the BRT corridor. As is shown in Table 5-3, 100% of the residential locations have job accessibility increase by public transport after the BRT constructed. All the maximum MAG values between different transport modes are below 0, which means the motorcycle still has a travel time advantage over public transport in BRT corridor. The MAG of MC_BB has the highest mean value which is -0.180 among all the four scenarios, meaning that, when congestion occurs, BRT included public transport system shows the most advantage among all the transport scenarios in accessing job opportunities. The increase of the MAG mean value is 7.5% and 12.1% respectively in no congestion situation and congestion situation. Depending on the concept of MAG (see page 17), for eco-friendly transport development, we should aim at pushing the MAG away from -1 towards 1. The MAG increase because of BRT can also be interpreted as BRT contributes to developing an eco-friendly transport system.

Table 5-3 Statistical Description of Job Accessibility Gap between Different Travel Modes

MAG Scenarios [8]	Maximum (MAG)	Mean (MAG)	Increase (MAG mean value)	Percentage of job accessibility increase area
B_M	-0.165	-0.305	7.5% (compare BB_M with B_M)	100% (compare BB_M with B_M)
BB_M	-0.160	-0.282		
B_MC	-0.074	-0.205	12.1% (compare BB_MC with B_MC)	100% (compare BB_MC with B_MC)
BB_MC	-0.007	-0.180		

[8] B_M: MAG between Bus and Motorcycle; BB_M: MAG between Bus & BRT and Motorcycle; B_MC: MAG between Motorcycle (congestion) and Bus; BB_MC: MAG between Motorcycle (congestion) and Bus & BRT

Figure 5-6 shows the job accessibility difference between different transport modes. The higher the MAG value means the job accessibility difference is smaller between motorcycle and public transport system. High MAG residential locations in south-west part generate a liner pattern in all four scenarios (Fig. 5-6), there is not dense road network and distribute bus stations and BRT stations there. Low MAG residential locations occupies most of the areas in the BRT corridor (Fig. 5-6 a), only some areas have high MAG value: near the city centre core, with high concentration of bus system, and rural areas without much bus system. It means people can get better accessibility by bus in areas where have intensive job locations, concentrated bus system, and the rural areas that take more time to reach job locations by motorcycle than by bus. Congestion situation (c and d) shows higher MAG than no congestion situation (a and b) reflects that people can get better job accessibility by public transport since motorcycle speed decreases under congestion situation.

When comparing (a) and (b) in Figure 5-6, a few areas in (b) along the BRT line get more improvement of job accessibility than (a), especially in the south-west area of the BRT corridor. People live in some part of the south-west areas can find more job opportunities after constructing the BRT. As high job density is concentrated in the north-east part of the corridor, and there is no dense road network in the end of south-west part. If congestion occurs, job accessibility of public transport is increased significantly (Fig.5-6 a and c), and it increases even more after the construction of the BRT (Fig.5-6 d).

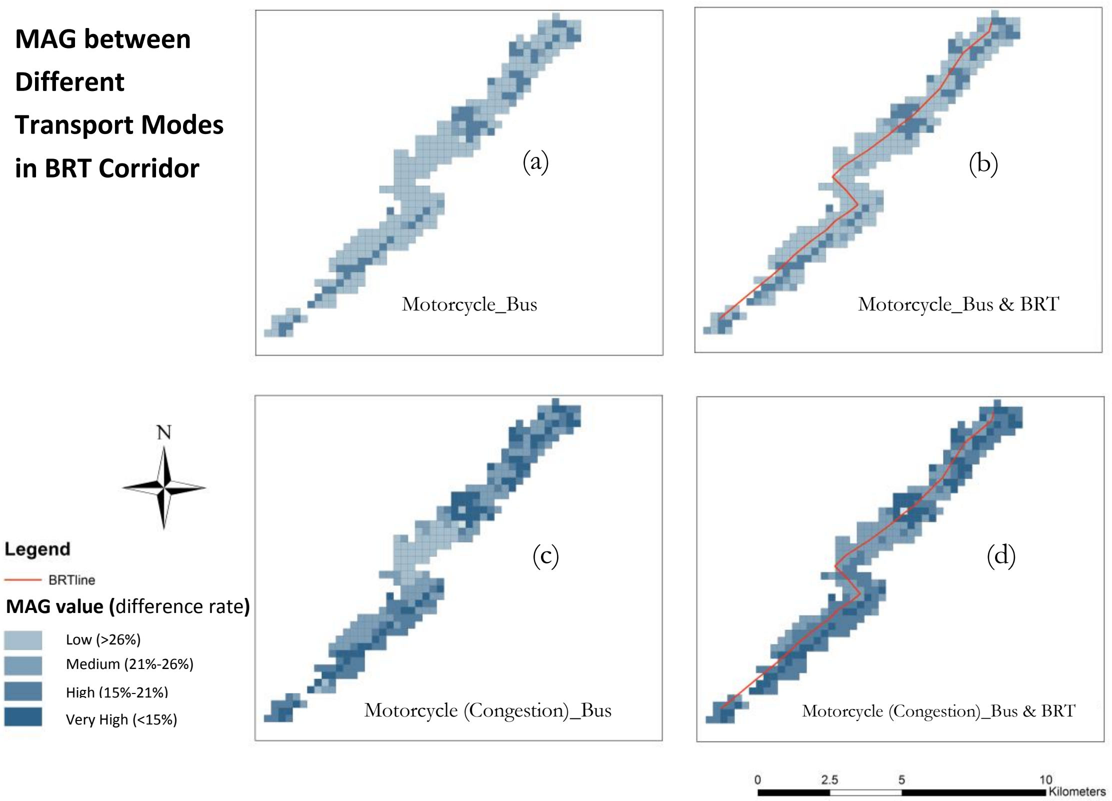


Figure 5-6 Job Accessibility Gap between Different Transport Modes in BRT Corridor

5.2. Indicator for CO_2 Emission

Motorcycle Volume

Figure 5-7 shows the modelled motorcycle volume per day in Hanoi city. The deeper the red colour means there is more motorcycle on that road. Most high motorcycle volume roads are in the north-east part and decline to the outer rural area. Also the main roads in Hanoi city have heavy motorcycle volume.

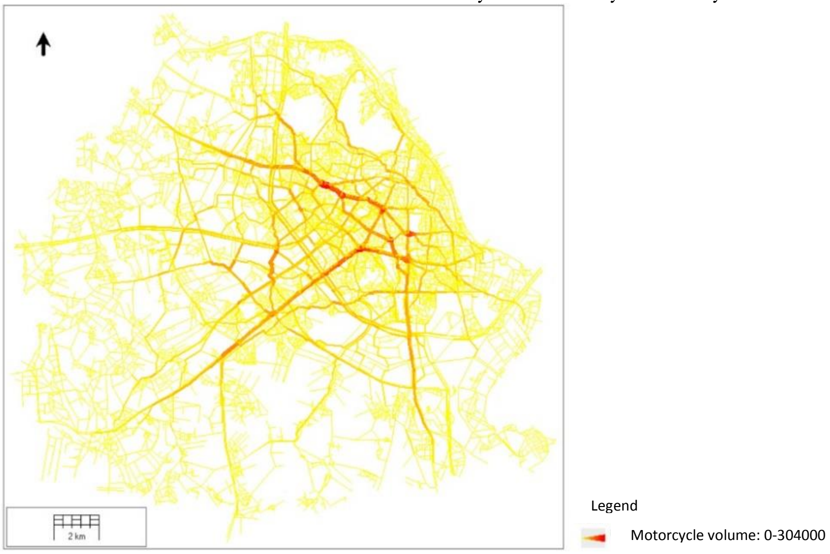


Figure 5-7 Motorcycle Volume in Hanoi City per Day

CO_2 Emission in Hanoi city

Motorcycle volume on the road network is the input data for computing CO_2 in 500*500 m resolution cells. The red areas are relatively high CO_2 emissions. High CO_2 areas are concentrated in the north-east part of Hanoi and decreases with the increasing of distance from the core (fig. 5-8). The high CO_2 emission areas have high distribution of residential locations. As analysed in the previous part, the impact of BRT is very small if we consider the entire city. The next section will be focusing on the selected BRT corridor.

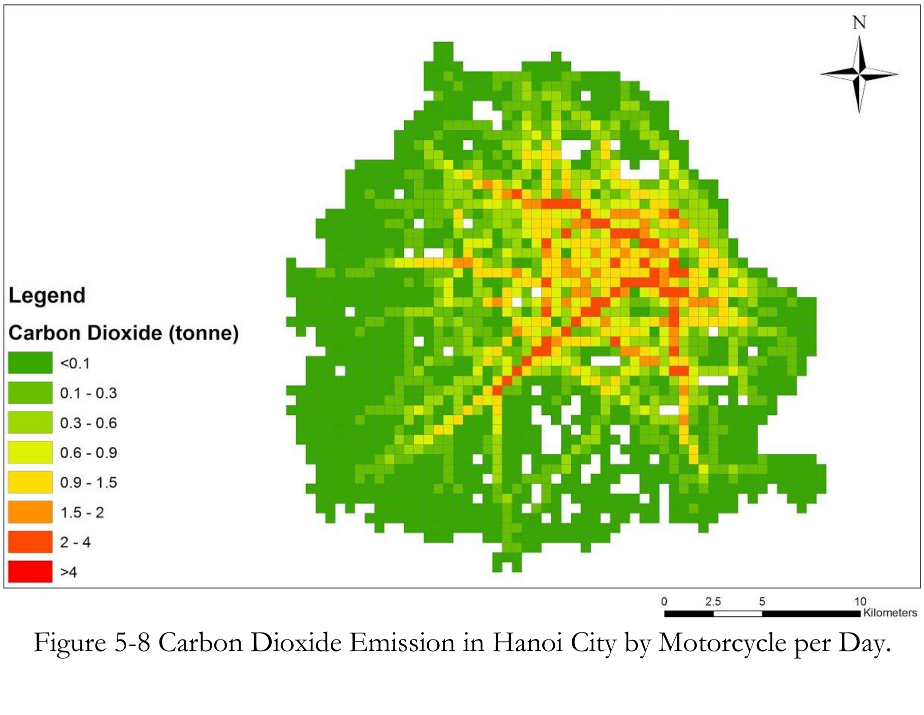


Figure 5-8 Carbon Dioxide Emission in Hanoi City by Motorcycle per Day.

CO_2 Emission in BRT Corridor

This section analysed the result of motorcycle CO_2 emissions in the BRT Corridor in three scenarios. Scenario 1: motorcycle CO_2 emissions without mode shifting; Scenario 2: motorcycle CO_2 emissions when some people shift from motorcycle to BRT; Scenario 3: motorcycle CO_2 emissions in congestion and some people shift from motorcycle to BRT.

Table 5-4 shows the total CO_2 emissions of motorcycles for each scenario. Comparing scenario 2 and scenario 3 with scenario 1, there is 2% and 4.3% CO_2 emissions decrease respectively. Three main reasons for this low decrease, (1) In Hanoi city, there is only one BRT line running from south-west to north-east part, people willing to shift from motorcycle to BRT only when they can travel faster by BRT than a motorcycle. (2) There are limited residential locations and job locations in the BRT corridor (3) with the limitation of data available, this research only considers the travel time difference between motorcycle and BRT. And if economic and convenient factors are considered in people's choice of travel modes, the construction of the BRT line may promote certain CO_2 emissions decreases along the BRT corridor.

Table 5-4 Statistical Description of Motorcycle CO_2 emissions in BRT Corridor per Day

Scenarios	Total CO_2 emissions (kg)	Decrease (compare with scenario 1)
Scenario 1	257,985	--
Scenario 2	252,825	2%
Scenario 3	249,729	4.3%

In south-west part of corridor area, there is one line in red reflect the area with relatively high CO_2 emission. This road is an urban main road in Hanoi. It is also the shortest route for most people live or work in the in south-west part of corridor area go to the city core areas. In the north-east part of the corridor area, medium level of emission occupies more than south-west part. As these areas are city core areas with relatively higher population density and job density than other areas. The traffic volume and CO_2 emissions on each road is higher than the roads in the outer area of urban Hanoi (Fig. 5-9). In the next section, this study will use Model Emission Gap to visualise the motorcycle CO_2 emissions change due to the small emission difference in the three scenarios.

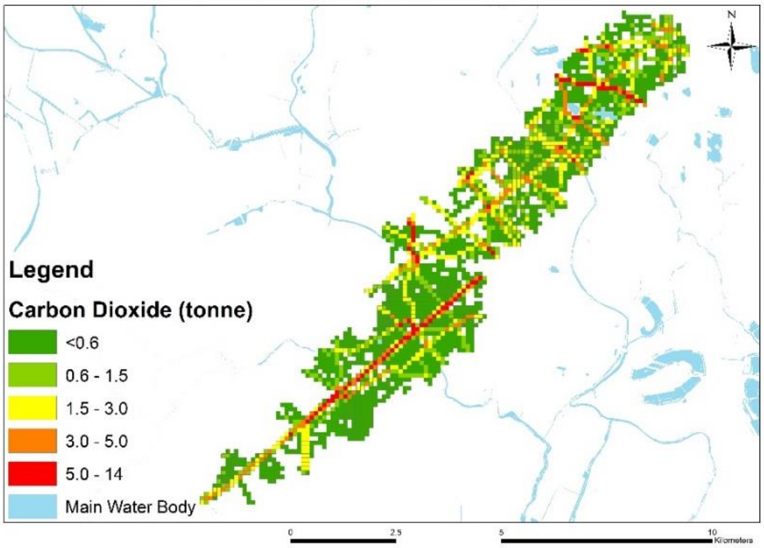


Figure 5-9 Motorcycle CO_2 Emission in BRT Corridor per Day. Cell resolution 100*100m.

Modal Emission Gap in BRT Corridor

This part aims to analyse the motorcycle CO_2 emission difference to see the effect of BRT under non-congestion (comparing scenario 1 with scenario 2) and congestion (comparing scenario 1 with scenario 3) condition. For the overall effect of BRT, the average MEG in the both conditions exceeds 0, which illustrates motorcycle CO_2 emissions decrease because of the BRT. The percentage of areas with CO_2 decrease are 45% and 77% (Table 5-5). Figure 5-10 shows the spatial distribution of the CO_2 emission decrease in the corridor area. In general, CO_2 emission in the north-east part decreases more than any other areas in the corridor, which own to this part is the city centre core with high population and job density, there are more people living there willing to shift to BRT. When congestion occurs, the CO_2 emission reduction level increases on almost all the roads in the north-east part, while in the south-west part, it only increases on the main roads with relatively heavy traffic. The reason is that under the congestion condition, people are more willing to use BRT to avoid being stuck in traffic jams thus decreases the amount of motorcycle emissions on these roads.

Table 5-5 Statistical Description of motorcycle CO_2 difference in BRT corridor

	Mean (MEG)	Percentage of area with CO_2 decrease
No Congestion	0.016	45%
Congestion	0.023	77%

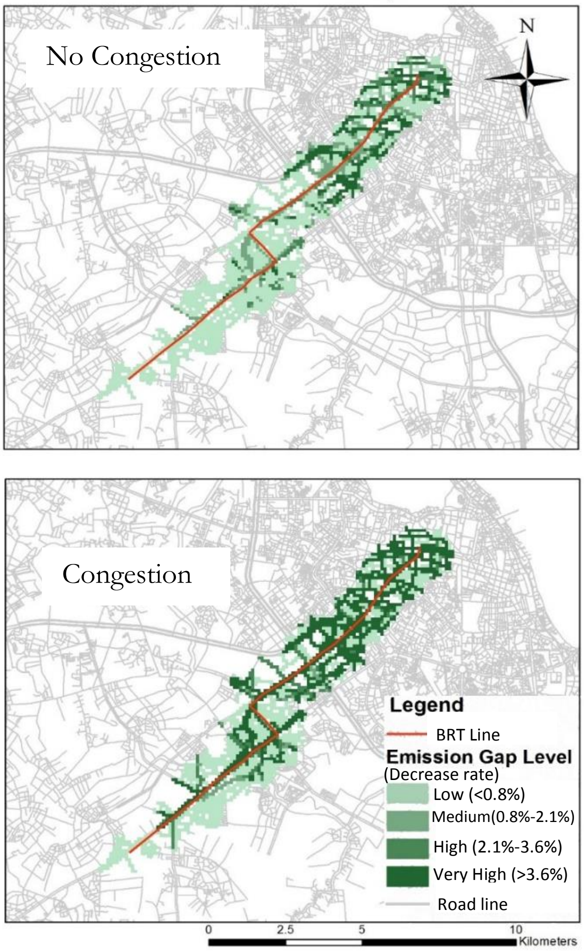


Figure 5-10 Model Emission Gap between Different Scenarios

6. CONCLUSIONS AND RECOMMENDATIONS

This chapter gives general conclusions and some recommendations for the future research. The conclusions are separated into two parts. One is for indicator Modal Accessibility Gap, another one is for indicator Modal Emission Gap. Following, this chapter provides some recommendations for the further studies, including a discussion about limitation and improving the two indicators.

6.1. Conclusion

Modal Accessibility Gap

This research used a modified version of the MAG model which derived from the study by Kwok & Yeh (2004). This adapted MAG model uses potential job accessibility measure without considering the non-time costs of travel such as parking fare, tolls, etc. The Potential job accessibility measure includes a decay function, which provides a reasonable mechanism to simulate people's travelling behaviour, the longer the distance the more difficult to reach job opportunities. This job accessibility gap analysis based on an adapted MAG model is applied on scenarios of comparing Motorcycle and Bus, Motorcycle and Bus & BRT, Motorcycle (congestion) and Bus, Motorcycle (congestion) and Bus & BRT for the whole Hanoi city and BRT corridor.

The result shows that:
(1) The locations with improvement of job accessibility mainly lie in the BRT corridor, however the effect of the BRT is very small in the whole city.
(2)The motorcycle has extremely potential job accessibility advantage over BRT.
(3) The BRT contributes to MAG value between motorcycle and public transport with an increase of 7.5% and 12.1% (in congestion). BRT promotes the mode shift from motorcycle to public transport.
(4) MAG is an effective indicator in evaluating the benefit level of specific areas from a public transport system in terms of job accessibility, even if they benefit a little. But the MAG value itself is a comparative job accessibility indicator, the improvement numbers in job opportunities cannot be interpreted.

Modal Accessibility Gap

MEG is an indicator proposed by this research based on MAG. Before implementing the MEG model, the vehicle emission (CO_2 in this case) is modelled in the first step. A 4-step transportation model is applied in this study to estimate the motorcycle CO_2 emission for the whole Hanoi city. After that motorcycle CO_2 emission is studied in the BRT Corridor to see the detail influence area with three transport scenario: (a) before the BRT is built, (b) some people shift to BRT and (c) motorcycle in congestion some people shift from motorcycle to BRT. Then no congestion and congestion condition is implement to compute MEG to evaluate the impact areas of BRT in terms of the reduction of motorcycle CO_2 emission.

The result reflects that:
(1) High CO_2 emission areas concentrate on the north-east part of Hanoi city and decreases along with longer distance from the city core to outer rural area. These areas also have many residential locations, this may cause health problems for the people living nearby.
(2) The proposed BRT line can reduce motorcycle CO_2 emission in the BRT corridor, but the reduction rate is very low which is 2% and 4.3% (congestion).
(3) CO_2 emissions in the north-west part decrease more than other areas in the corridor, people living in these areas benefit from BRT because of the reduction of CO_2 emission, especially when congestion occurs.(4) MEG in an effective comparative indicator for reflecting the specific emission decrease areas as

a result of constructing a new public transport system, even if the reduction amount is very small. But it doesn't reflect the decrease amount of emissions.

6.2. Limitations and Recommendations

This section gives some limitations and recommendations for the future research, two parts included: limitations and recommendations for MAG and MEG. In general the entire approach of this research is based upon travel time alone, but in reality, people includes many other considerations (cost, convenience, safety, etc.) for mode choice, thus, further researches are able to add some other element in addition to travel time.

Modal Accessibility Gap

In terms of MAG, first, this study uses an adapted MAG model, this adapted MAG model uses a potential measure without considering the cost of travel include parking fare, tolls, etc. Thus, the further research can consider the travel cost like travel fare for both private transport and public transport.

Second, in Hanoi city bicycle has almost 30% mode share, this research doesn't combine bicycle with Bus and BRT. It only assumes that after taking a bus or BRT people all walk to their home or job locations. The public transport is crowded and the parking facility around the public transport system area is limited, but some projects have planned for some parking areas. So, it is meaningful to combine bicycle with Bus and BRT.

Third, this research only applied the congestion scenario to study the effect of BRT based on MAG. More policy scenarios can be applied for the further research. For example, If government improves the job opportunities in certain area, whether the effect of BRT will improve or not. Meanwhile, MAG is not necessarily confined to evaluate the effect of BRT but can also be used for expansion of the system in Hanoi. If the MAG is between public transport and private transport, low MAG locations is lack of public transport system, so MAG can be considered as an indicator for expansion the BRT line.

Modal Emission Gap

For MEG, first, this study uses the 4-step model to estimate the CO_2 emission, with the limitation of data availability, the mode split part doesn't included, so, further study can use social-economic data by applying (for example binomial logit model) to predict the mode use.

Then, for estimating and spatial distributing mode shift, a survey decay function is applied, this function only considers the time difference, the same with the previous part, travel cost like travel fare for both private transport and public transport can be considered.

Finally, MEG is computed by summing up emission on roads within cells. Future research could include how emission disperses from road to surrounding areas.

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Appendix A: Reclassification of job type

Number	Land use category	Sector	Total number of jobs (people)	Summed total number of jobs (people)
1	Industry	Mining	8,108	513,091
		Manufacturing industry (including textile, garment, paper, etc.)	496,705	
		Electricity, gas, steam	8,278	
2	Business	Private trade and services (small trade along streets)	191,681	896,686
		Construction	223,438	
		Whole sales and retail trade, repair of motor vehicles and motorcycles	254727	
		Accommodation and food services (Hotel, restaurant)	71,085	
		Information and communication	43,746	
		Financial, banking and insurance	9,035	
		Real estate	14,192	
		Personal and public services	8,277	
		Property business and consulting service	37,135	
		art, entertainment and recreation	6,256	
		Agriculture-Forestry-Fishery	7,114	
3	Social service	Communist party, socio-political organization and defence	3,567	298,293
		Administration and support services	15,169	
		Science and technology	59,085	
		Administration in education field	48,919	
		Administration in Healthcare field	14,084	
		Doctor	5,923	
		Assistant to doctor	2,364	
		Nurse	4,983	
		Pharmacists	845	
		Lecturer in university and college	16,541	
		Teacher in technical vocational college	2,970	
		Teacher in kindergarten	6,935	
		Teacher in Primary school	19,332	
		Teacher in Secondary school	19,414	
		Teacher in high school	8,118	
		Transportation and storage	51,753	
		Cultural and sporting services	4,861	
		Tourist services	5,007	
		Water supply, sewerage, waste management	8,423	

Appendix B: Reclassification of Land Use

Number	Reclassified land use type	Original land use type
1	Industry	Heavy Industry
		Industry
		light industry
2	Business	Hotel
		Business and production enterprise
		Market
		Post Centre
		Supermarket
		Historical and Tourist area
		Exhibition Area
		Cinema
		Agriculture
3	Social service	Administrative Office
		Hospital
		Health Clinic
		Education Centre
		Research Institute
		School
		School-high
		School-infant
		School-Primary
		school-primary and secondary
		school-secondary
		school-secondary and high
		University College
		Library
		Inland Port
		Railway Station
		City bus station
		Gasoline station
		Church
		Museum
		Community Hall
		Sport centre
		Stadium
		Tourist area
		Water pump station
4	Residential	New urban area
		Urban area
		Urban residential
		Village
		Village urban
5	Forests & Nature sites	Park
		Forest
6	Water body	Water body

Appendix C: Nature Breaks Classification

A method of manual data classification that seeks to partition data into classes based on natural groups in the data distribution. Natural breaks occur in the histogram at the low points of valleys. Breaks are assigned in the order of the size of the valleys, with the largest valley being assigned the first natural break (Howard, 2008).

GVF, the Goodness of Variance Fit is related with the fulmar as follows:

$$SDCM = \sum_{j=1}^{k} \frac{1}{N_j} \sum_{i=1}^{N_j} \left(z_{ij} - \overline{z}_j\right)^2 \quad (21)$$

$$SDAM = \frac{1}{\mathrm{N}} \sum_{i=1}^{N} \left(z_i - \overline{z}\right)^2 \quad (22)$$

$$GVF = 1 - \frac{SDMC}{SDAM} \quad (23)$$

Where, SDAM is the Sum of squared Deviations from the Array Mean, which is the squared deviation of original data; SDCM is the Sum of squared Deviations about Class Mean. Obviously, SDAM is a constant value, and SDCM is related with categories k. In a certain range, the higher of GVF, the better of the classification result. The smaller the SDCM, the higher the GVF, approach to 1. The increase of SDCM related with k, when k equals n, SDMC=0, GVF=1. That reflects that the bigger the k, the bigger the GVF.

Table Appendix E GVF Score of Different Classification Method

Classification Method	GVF
Defined Interval	0.7203
Equal Interval	0.7128
Quantile	0.7271
Natural Breaks	0.8524
Standard Deviation	0.8137

From the table we can see that the natural breaks method has obvious advantage than other methods that is because in GVF, SDCM is the sum of squared Deviations in natural breaks. When SDMC is the smallest, thus GVF is the highest. So natural breaks is the optimal method among all the methods.

Appendix D: MAG between Different Transport Modes