Consideration of Health Impacts in Transport Demand Modelling and Management

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Vom Fachbereich Bau- und Umweltingenieurwissenschaften der Technischen Universität Darmstadt zur Erlangung des akademischen Grades eines Doktor-Ingenieurs genehmigte Dissertation

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Titel der Dissertation: Consideration of Health Impacts in Transport Demand Modelling and Management
Dissertationsort: Darmstadt, Technische Universität Darmstadt

Tag der Einreichung: 21.06.2021
Tag der mündlichen Prüfung: 07.09.2021

Jahr der Veröffentlichung der Dissertation auf Tuprints: 2021

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Schriftenreihe der Institute für Verkehr
Institut für Verkehrsplanung und Verkehrstechnik
Heft V48

ISSN 1613-8317

Acknowledgements

I want to express my gratitude towards institutions and individuals who have helped tremendously during my four-year study in Germany.

Firstly, I would like to thank the Vietnamese Ministry of Education and Training (MOET) for sponsoring my study. This has helped me pursue my dream, which is a doctoral degree. My thanks are also extended to World University Service (WUS) in Hessen state. WUS helped me with accommodation, visa service, and some information on events for Vietnamese students.

Secondly, I would like to express enormous gratitude to my “Doktorvater” Professor Manfred Boltze, Chair of Transport Planning and Traffic Engineering, Technische Universität Darmstadt. The acceptance of Professor Boltze opened the door for me to study at a prestigious university and institute. Under the guidance of Professor Boltze, step by step, I enhanced my knowledge, improved my academic skills and completed the course. My Doktorvater has influenced me with professional knowledge and his vision in one of the most crucial times of my life. I will never forget all of the critical feedback and enthusiastic encouragement from Professor Boltze.

I would also say many thanks to my second supervisor Professor Bhargab Maitra. Professor Maitra gave me a lot of valuable comments on my work. I have had several interesting interactions with him in the International Doctoral Seminar and via zoom meetings. The generous support from Professor Maitra has assisted me in completing my dissertation.

During my study at the Institute of Transport Planning and Traffic Engineering (IVV), I have had an excellent opportunity to meet and interact with my colleagues. The first one, I would like to say many thanks to Dr. Ögür Öztürk. Dr. Öztürk was my first official partner. At that time, we had a lot of exciting exchanges of culture and life in Germany. In my final process, Dr. Öztürk was my mentor, who gave me many valuable comments. The second one is Mrs. Nicole von Stetten. I always received kind support from her during my studies in IVV. My heartfelt thanks to my colleagues in IVV, Marc Lüke, Dr.-Ing. Moritz von Mörner, Dr.-Ing. Kevin Rolko, Wei Jiang, Regina Linke, Dr.-Ing Tobias Monzert, Karin Menges, Danny Wauri, Kim Wilke, Jürgen K. Wilke, Kristin Follmann, Sunghyun Jang, Ferdinand Schöpp, Le Thi Huong, and Xiaochen Yu, with whom I share warm friendship. They gave me many excellent comments in conferences, in my works and in the final defense. Thanks to them, I survived two very rough years of the Covid 19 pandemic.

My thanks are also to my colleagues at the Department of Road and Urban Transport, University of Transport and Communication, Hanoi, Vietnam. They not only couraged me to pursue my research but also supported my data collection.

To my family, from the bottom of my heart, I would say my deepest thanks to my beloved wife, Tran Thi Kim Thoa. The encouragement of my wife has helped me through several difficult times. She also helps me take care of our children while I cannot be home. To our children, I am missing them so much and hoping that I can come back home as soon as possible. To my parents, I would like to express my gratitude for their continuous support. This result is a big gift for my father, who has been my biggest life mentor.

Abstract

Urbanization leads to motorised transport in both, developed and developing countries. Particularly, in developing countries motorised transport has become primarily cause of negative health impacts such as air pollution, noise pollution, traffic accidents etc. Several studies illustrate that private vehicle use causes negative health impacts while public transport use has less negative health impacts and active transport use even supports human health. Therefore, influencing mode choice behaviour plays a pivotal role to change health impacts of transport. To pursue this objective, this study is carried out in two phases. In the first phase, a state-of-the-art mode choice model is developed, which analyses the change of mode choice behaviour. In the second phase, consideration of health impacts in transport demand management aims at influencing mode choice behaviour of travellers.

There are several studies on developing mode choice models which are based on an analysis of mode choice behaviour. However, there is a lack of research which considers health impact awareness as an influencing factor in the mode choice model. Filling this gap, this study reviews the state of development in transport demand modelling, then proposing a model development process. Applying this process, a transport mode choice model with consideration of health impact awareness is developed.

Experience from developed countries such as European countries, the United States of America, Australia, Singapore and other countries illustrates that transport demand management is effective in changing traveller’s behaviour. The change of mode choice behaviour has helped to reduce negative health impacts of transport in developed countries, already. Following the experience of developed countries, the state of development in transport demand management with consideration of health impacts is reviewed. From that, the lists of transport demand management measures are collected. Finally, the German method to develop transport demand management strategies is explained.

The newly developed mode choice model is applied for the case study of Hanoi, Vietnam. For this city, the traffic situation, the transport planning strategies and the health impact problems are explained. The results of the model application confirm that mode choice behaviour of travellers is affected by seven explanatory variables and five latent variables. It is demonstrated that health impact awareness influences mode choice behaviour significantly. Corresponding to the identified health problems, transport demand management measures are selected. These measures were combined to strategies for the case of Hanoi, following the German method to develop transport demand management strategies. Based on results from the mode choice model, this study finally simulates the change of mode choice behaviour in some scenarios of transport demand management measures and strategies, thereby, demonstrating the effectiveness of this approach.

In summary, this study enriches research on health impacts of transport in developing countries. The results show that novel factor health impact awareness is a significant influence on mode choice behaviour. The results also reveal that transport demand management is feasible to be applied for the case study of developing countries. The implementation of transport demand management is effective to reduce negative health impacts from transport and to support human health.

Kurzfassung

Die Urbanisierung führt sowohl in Industrie- als auch in Entwicklungsländern zu motorisiertem Verkehr. Insbesondere in Entwicklungsländern ist der motorisierte Verkehr die Hauptursache für negative Gesundheitswirkungen wie Luftverschmutzung, Lärmbelästigung, Verkehrsunfälle usw. Mehrere Studien zeigen, dass die Nutzung von individuellen Kraftfahrzeugen negative Auswirkungen auf die Gesundheit hat, während die Nutzung öffentlicher Verkehrsmittel geringere negative Auswirkungen auf die Gesundheit hat und die Nutzung aktiver Verkehrsmittel die menschliche Gesundheit sogar unterstützt. Daher spielt die Beeinflussung des Verkehrsmittelwahlverhaltens eine entscheidende Rolle bei der Veränderung der gesundheitlichen Auswirkungen des Verkehrs. Um dieses Ziel zu verfolgen, wird diese Studie in zwei Phasen durchgeführt. In der ersten Phase wird ein Verkehrsmittelwahlmodell nach dem aktuellen Stand der Technik entwickelt, das die Veränderung des Verkehrsmittelwahlverhaltens analysiert. In der zweiten Phase zielt die Berücksichtigung von Gesundheitsauswirkungen im Verkehrsnachfrage-management darauf ab, das Verkehrsmittelwahlverhalten der Reisenden zu beeinflussen.

Es gibt mehrere Studien zur Entwicklung von Verkehrsmittelwahlmodellen, die auf einer Analyse des Verkehrsmittelwahlverhaltens basieren. Es fehlt jedoch an Untersuchungen, die das Bewusstsein für gesundheitliche Auswirkungen als Einflussfaktor im Verkehrsmittelwahlmodell berücksichtigen. Um diese Lücke zu schließen, wird in dieser Studie der Stand der Entwicklung in der Verkehrsnachfragemodellierung überprüft und darauf aufbauend ein Modellentwicklungsprozess vorgeschlagen. Unter Anwendung dieses Prozesses wird ein Verkehrsmittelwahlmodell entwickelt, welches das Bewusstsein für gesundheitliche Auswirkungen berücksichtigt.

Erfahrungen aus Industrieländern wie Europa, den Vereinigten Staaten von Amerika, Australien, Singapur und anderen Ländern zeigen, dass das Verkehrsnachfragemanagement das Verhalten der Reisenden effektiv verändern kann. Die Änderung des Verkehrsmittelwahlverhaltens hat in den Industrieländern bereits dazu beigetragen, die negativen gesundheitlichen Auswirkungen des Verkehrs zu mindern. Ausgehend von den Erfahrungen der Industrieländer wird der Entwicklungsstand des Verkehrsnachfragemanagements unter Berücksichtigung der gesundheitlichen Auswirkungen untersucht. Davon ausgehend werden Maßnahmen zur Beeinflussung der Verkehrsnachfrage zusammengestellt. Abschließend wird die deutsche Methode zur Entwicklung von Strategien zur Verkehrsnachfragebeeinflussung erläutert.

Das neu entwickelte Verkehrsmittelwahlmodell wird für die Fallstudie von Hanoi, Vietnam, angewendet. Für diese Stadt werden die Verkehrssituation, die Strategien der Verkehrsplanung und die Probleme gesundheitlicher Auswirkungen erläutert. Die Ergebnisse der Modellanwendung bestätigen, dass das Verkehrsmittelwahlverhalten der Reisenden von sieben erklärenden Variablen und fünf latenten Variablen beeinflusst wird. Dabei zeigt sich, dass das Bewusstsein für gesundheitliche Auswirkungen einen signifikanten Einfluss auf das Verkehrsmittelwahlverhalten hat. Entsprechend der identifizierten Gesundheitsprobleme wurden Maßnahmen zur Verkehrsnachfragebeeinflussung ausgewählt. Diese wurden dann nach der deutschen Methode in Strategien zur Verkehrsnachfragebeeinflussung kombiniert. Basierend auf den Ergebnissen des Verkehrsmittelwahlmodells simuliert diese Studie schließlich die Veränderung des

Verkehrsmittelwahlverhaltens für einige Szenarien von Maßnahmen und Strategien des Verkehrsnachfragemanagements und demonstriert damit die Effektivität dieses Ansatzes.

Zusammenfassend bereichert diese Studie die Forschung über gesundheitliche Auswirkungen des Verkehrs in Entwicklungsländern. Die Ergebnisse zeigen, dass der Faktor Gesundheitsbewusstsein einen signifikanten Einfluss auf das Verkehrsmittelwahlverhalten hat. Die Ergebnisse zeigen auch, dass Verkehrsnachfragemanagement für die Fallstudie der Entwicklungsländer angewendet werden kann. Eine solche Anwendung des Verkehrsnachfragemanagements ist effektiv, um negative Gesundheitsauswirkungen des Verkehrs zu reduzieren und die menschliche Gesundheit zu unterstützen.

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1 Introduction

This chapter gives a brief introduction to motivation, goals and objectives, methodology, structure, and the research question of this study.

1.1 Motivation

The 21st century is the era of urbanisation. Fifty-four percent of the world's population lives in urban areas (United Nations, 2014). According to the United Nations (2018), at the turn of the century in 2000, there were 371 cities with 1 million inhabitants or more worldwide. By 2018, the number of cities with at least 1 million inhabitants had grown to 548. It is predicted that by 2030, the world will have 706 cities with at least 1 million residents.

According to Dobbs et al. (2011), 600 urban centres of the world contribute 60 percent of global gross domestic product (GDP). Higher GDP per capita leads to more private vehicles (Kahn Ribeiro et al. 2007)**.** In this way, urbanisation is the primary cause of motorised transport in developed and developing countries. The number of private vehicles in developing countries is predicted soon to exceed those in developed countries (Wright & Fulton 2005). Particularly in many Asian cities, motorised two- and three-wheeled vehicles dominate the transport system, accounting for 50-80% of all vehicles (Tobish 2007).

Poor public transport system and lack of active transport infrastructure and networks together with an increasing numbers of private vehicles lead to the increase of private vehicle use in developing countries*.* Studies have demonstrated that private vehicle use is a primary cause of adverse health impacts (WHO 1998, WHO 2004, Dora et al. 2011, WHO 2012, WHO 2014). The report "The global burden of disease" shows that road traffic accident is one of the top-ten leading causes of death in the world (WHO 2004, WHO 2014). The WHO regional publication, European series, No.89 "Transport, environment and health" revealed the detrimental health impacts of transport noise, accidents, air pollution and the effects of transport on mental health and well-being (WHO 1998). The HEARTS project "Health effects and risks of transport systems" assessed the impacts of urban transport on health, in which traffic-related air pollution, noise, crashes and social effects are analysed as negative health consequences (WHO Regional Office for Europe 2006). Module 5g in the Sourcebook on Sustainable Urban Transport "Urban transport and health" illustrated the health challenges for the transport sector including air pollution, road traffic injuries, lack of physical activity, noise pollution, climate change, land use, access, and social well-being (Dora et al. 2011). These problems can be solved by both, transport supply and transport demand procedures. However, in developing countries, transport supply procedures are unfeasible to solve transport problems and negative health impacts immediately because of the physical constraints and limited financial resources. Therefore, it is very important to focus on transport demand procedures for case of developing countries.

Urbanisation brings both positive and negative impacts on human life. It boosts economic growth. At the same time, it promotes more private vehicle use, which generates various environmental and traffic problems as well as adverse health impacts, particularly in developing countries. Hence, negative health impacts will continue to worsen in developing countries if the tendency to increase private vehicle use does not change. This leads to the main question for this study:

How can the transport mode choice behaviour of travellers be changed?

To answer this question, this study focuses on the following operations.

Firstly, the change in traveller's behaviour, such as in mode choice, leads to a change in health impacts from motorised road transport. To understand the changes of mode choice behaviour, there are numerous scientific papers which develop transport mode choice models based on the fields of economics, psychology, and transport research, such as McFadden (2000), Ajzen (1991), Prochaska & Velicer (1997), Ortúza & Willumsen (2011), Ben-Akiva & Lerman (1997), and Train & McFadden (2002). However, until today, there is no model which can be used to analyse mode choice behaviour taking account of the traveller's perception of health-related information. Since the awareness of travellers plays a vital role in changing their behaviour, the transport mode choice model in this study examines how health impacts awareness influences the traveller's behaviour.

Secondly, in dealing with the health impacts from road transport in urban areas, the research of Dora et al. (2011) mentions much experience in European countries, such as with improved transport demand management. From the improvements in European countries, negative health impacts have been reducing for thirty years. Since transport demand management is effective in changing traveller’s behaviour, transport demand management measures and strategies which incorporate health impact information are the second consideration of this study.

1.2 Objective and scopes of the study

The objective of this study is to consider health impacts in transport demand modelling and management. In pursuit of this, the scopes of the study include:

- Reviewing the research on the health impacts of transport in order to define concepts and find gaps in the research.
- Developing a transport demand model which can consider the traveller's perception of health impacts.
- Reviewing studies of transport demand management to determine possible transport demand management measures taking account of the health impacts of urban transport.
- Applying a transport demand modelling process for the case study in Hanoi, Vietnam. Analysing the influence of health impact awareness and other factors on the changes in travellers' mode choice behaviour.
- Considering health impacts in transport demand management for the case study of Hanoi, Vietnam. Selecting effective transport demand management measures and developing strategies influencing traveller’s behaviour.

To implement these scopes of the study, research questions and methodologies are shown in the next section.

1.3 Methodology, structure and research questions of the study

Following the scopes of the study and applying the methodology of the German Transport Planning Process (FGSV, 2001 and 2008), the structure of this research and corresponding research questions are provided in Table 1.1 as follows.

Table 1.1 Chapters and research questions

Chapters		Research questions
Chapter 1: Introduction		
Chapter 2: Health impacts of transport	Q1: Q2:	How can health impacts in transport be defined? What is the status quo of research on health impacts in transport?
Chapter 3: Transport demand modelling under consideration of health impacts	Q3:	How can a transport demand model be developed?
Chapter 4: Transport demand management under consideration of health impacts	Q4: Q5:	What transport demand management measures are feasible? How can transport demand management strategies be developed?
Chapter 5: Case study: Transport demand modelling and management in Hanoi (Vietnam)	Q6: Q7: Q8: Q9	What is the status quo of transport and health impacts in Hanoi, Vietnam? How do health impact awareness and other factors affect mode choice behaviour in Hanoi, Vietnam? Which transport demand management measures are suitable for the case study of Hanoi, Vietnam? Which transport demand management strategies can be implemented to change transport mode choice behaviour for the case study of Hanoi, Vietnam?
Chapter 6: Conclusions		

Chapter 1 gives motivation, goal, objectives, methodology, structure and research questions of this study.

Chapter 2 reviews research on health impacts of transport. The central concept of this study "health impacts of transport" will be defined. This chapter reveals the deficiencies of past studies and opportunities for new research on the health impacts in transport demand modelling and transport demand management.

Chapter 3 reviews the state of development in transport demand modelling. Next, a process which develops the transport demand model is proposed. The steps in the process of transport demand model development will be applied to develop a state of the art model which can answer the question of how health impact awareness and other factors influence mode choice behaviour.

Chapter 4 reviews studies of transport demand management. It categorises and analyses transport demand management measures. This chapter shows where suitable measures for health impacts in transport systems can be applied. Strategy formation is presented in this chapter.

The first section of **Chapter 5** analyses the transport and health impact situation in the case study of Hanoi. The next section applies the process of transport demand model development to the case study of Hanoi, Vietnam. Models can be used to analyse the change of choice behaviour of travellers under the influencing factors. The final section selects feasible traffic management measures and develops traffic management strategies which consider health impacts for a case study of Hanoi Vietnam.

Chapter 6 presents the summary, major conclusions, limitations and future scope of work of this study.

2 Health impacts of transport

The first section of this chapter presents the key definitions which relate to health impacts of urban transport. Then, the interdependencies of urban form, transport and health are discussed. The next section shows the existing regulations and thresholds regarding health impacts. In the final section, studies that are related to health impacts are reviewed to determine the gaps in research on the health impacts of transport. This provides orientation for the next steps of this study.

2.1 Key definitions and interdependencies between urban form, transport and health impacts

This section presents key definitions which relate to health impacts of transport. Then the interdependencies of urban form, transport and health impacts are discussed.

2.1.1 Key definitions

In general, the term "health" is the condition of the human body or mind or state of being well. The concept of **health** is defined in the constitution of the World Health Organization (WHO): *"Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity"* (WHO Constitution, 2006).

In the context of this study, **health impacts** are influences from transport activities on human health. Transport activities can cause negative human health by air pollution, noise pollution, psychological stress and traffic accidents or positive human health through physical activities such as walking or cycling.

To assess the impacts of air pollutants on human health, Ott (1982) defined the concept of **health exposure**: that is *"a person comes in contact with concentration of pollutants at a particular instant of time".*

In general, the term "effect" means the result of a particular influence. In this study, **health effects** are particular influences of health impacts such as diseases or death.

Pathway is a process which is presented step by step from sources to health effects**.** Based on the definition of Ott (1982), WHO (2006) revealed the pathway from sources to health effects, as follows:

"Sources → Emissions → Concentrations → Exposure → Dose → Health effects"

Source: WHO (2006)

As can be seen in the pathway above, the different sources lead to different emissions. Walking and cycling have zero emissions, and using public transport modes produces low pollutant emissions. Private vehicles such as cars and motorcycles which use energy sources from fossil fuels generate more harmful emissions than other transport modes. Emissions are concentrated in different places and times. Human exposure only occurs when people have contact with pollution concentrations. The dose depends on the characteristics of the exposure and the pollutants as well as personal activities, skin condition, etc. Heath effects depend on previous stages in the environmental pathway. Hence, people can change health effects of air pollution by changing any of the stages in this pathway.

To support the understanding of terms in this study, the terms related to health impacts are presented in Figure 2.1.

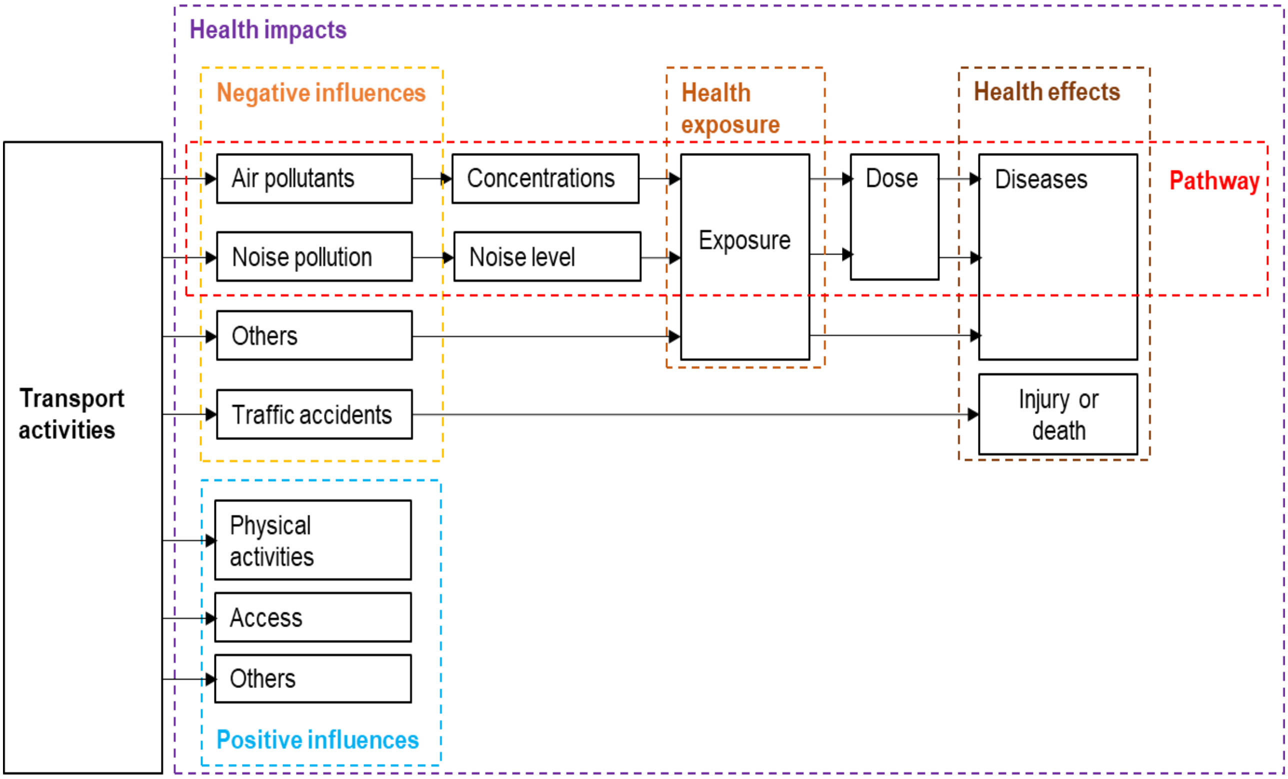

Figure 2.1 Terminologies related to health impacts of transport activities

Source: Author's representation

Ambient air "*means the outdoor air in the troposphere, excluding workplaces"* (Directive 2008/50EC of the European Parliament and of the Council 2008).

Environmental noise "*means unwanted or harmful outdoor sound created by human activities, including noise emitted by means of transport, road traffic, rail traffic, air traffic, and from sites of industrial activity*" (Directive 2002/49/EC of European Parliament and of the Council 2002).

Annoyance "*means the degree of community noise annoyance as determined by means of field surveys*" (Directive 2002/49/EC of European Parliament and of the Council 2002).

Dose-effect relation "*means the relationship between the value of a noise indicator and a harmful effect*" (Directive 2002/49/EC of European Parliament and of the Council 2002).

Some further terms related to air quality standards and emission limits are defined in Table 2.1.

Table 2.1 Terms and definitions related to air quality standard and emission limits

Terms	Definitions
Alert threshold	a value which, if exceeded in the event of short-term exposure, is at risk to the health of the general population and must be taken without delay
Immission limit value	a value established on the basis of scientific evidence with the aim of preventing or reducing harmful effects on human health or the environment as a whole, and which must be complied with within a specified period of time and must not be exceeded thereafter
Critical value	a value established on the basis of scientific evidence, the exceeding of which may have direct adverse effects on some receptors such as trees, other plants or natural ecosystems, but not on humans
Nitrogen Oxides	the sum of the volume mixing ratios of nitric oxide and nitrogen dioxide expressed in the unit of the mass concentration of nitrogen dioxide in micrograms per cubic metre
Particles matter PM_{10}	particles that pass through a size-selective air inlet with a 50 percent separation degree for an aerodynamic diameter of 10 microns
Particles matter $PM_{2.5}$	particles passing through a size-selective air inlet with a 50 percent separation degree for an aerodynamic diameter of 2.5 microns
Arsenic, Cadmium, Nickel and Benzo[a]pyrene	the total content of the element or compound in the PM_{10} fraction
Pollutant	any substance present in ambient air and likely to have harmful effects on human health and/or the environment as a whole
Level	the concentration of a pollutant in ambient air or the deposition thereof on surfaces in a given time
Volatile organic compounds (VOC)	organic compounds from anthropogenic and biogenic sources, other than methane, that are capable of producing photochemical oxidants by reactions with nitrogen oxides in the presence of sunlight

Source: This issue is covered in ‘Ordinance on Air Quality Standards and Emission Limits-39. BlmSchV’ (2020) and ‘Directive 2008/50EC of the European Parliament and of the Council 2008’

2.1.2 Interdependencies between urban form, transport and health

Transport is an activity that can support human health or can cause adverse health impacts. There are numerous studies which explore **the link between transport and health outcomes** (WHO 1998, WHO Regional Office for Europe 2006, WHO 2012, Gebel 2012, WHO 2014, Mueller et al. 2017).

Khreis et al. (2019) developed a conceptual model which describes a framework of the **relationship between transport and health effects,** as shown in Figure 2.2. According to Khreis et al. (2019)**,** the process from transport system to health impacts is triggered by four aspects which are land use and the built environment, transport infrastructure, transport mode choice, and transport technologies and disruption. Three aspects: land use and the built environment, transport infrastructure, and transport technology and disruption indirectly influence human health while transport mode choice directly impacts on human health. Hence, transport mode choice plays a significant role in improving human health.

The four aspects which are mentioned above affect human health through 14 health exposures: greenspace and aesthetics, physical activity, access, mobility independence, contamination, social exclusion, noise, urban heat islands, vehicle crashes, air pollution, community severance, electro-magnetic fields, stress and greenhouse gas emissions.

Four of these health exposures are linked to beneficial health effects:

- **Green space** is land that is covered by grass, trees, shrubs, or other vegetation in public areas. Greenspace supports physical activities and reduces urban heat islands, air pollutants and noise pollution.
- **Physical activity** relates to the human body's energy expenditure, such as walking or using active transport (e.g. bicycles). Lack of physical activity leads to some problems with human health.
- **Access** is the ability to reach public transport, facilities of active transport and health facilities. Reducing distance is a measure which encourages more users of public and active transport.
- **Mobility** is the capacity of different population cohorts to use various transport modes.

Other of these health exposures are linked to adverse health effects:

- **Contamination** is caused by harmful substances such as oils, gasoline, heavy metals, particulate matter, and polycyclic aromatic hydrocarbons due to motor vehicle traffic.
- **Social exclusion** limits the opportunity to engage in community and social activities. This factor relates to affordability, accessibility, availability, geographical location, time and fear.
- **Noise pollution** from vehicle sounds can reach a dangerous health level. The noise level depends upon road networks, junctions, traffic flows, and vehicle speed.
- **Urban heat islands** are caused by high air temperatures, heatwaves, or radiation. These issues cause psychological stress. In some particular situations, urban heat islands cause fatalities. In nine days in August 2003, the number of deaths caused by heatwaves in France was 15,000 (Fouillet et al. 2006). In July 2006, in California, research by Ostro et al. (2009) proved that a heatwave was the cause of 147 deaths and over 16,000 emergency department cases. Gabriel & Endlicher (2011) have proved that heatwaves increase mortality rates, particularly in the city of Berlin.
- **Vehicle crash** is a factor that affects human health, as is shown in several reports of the WHO. Traffic accidents inflict a burden on both individuals and society by causing death, injury and disability.
- **Air pollution** from transport contains several substances, which have a direct and severe influence on human health.
- **Community severance** relates to transport infrastructure and motorised traffic that separates places and people.
- **Electro-magnetic fields** can be created by differences in voltage and can be present near electricity generation stations, electric grids, and other similar infrastructure.
- **Stress** is associated with travel and results from increased travel time, congestion, searching for parking space, interaction with other drivers, and collision or traffic accidents.
- **Greenhouse gas** emissions are carbon dioxide, methane, nitrous oxide, and fluorinated gases that trap heat in the atmosphere.

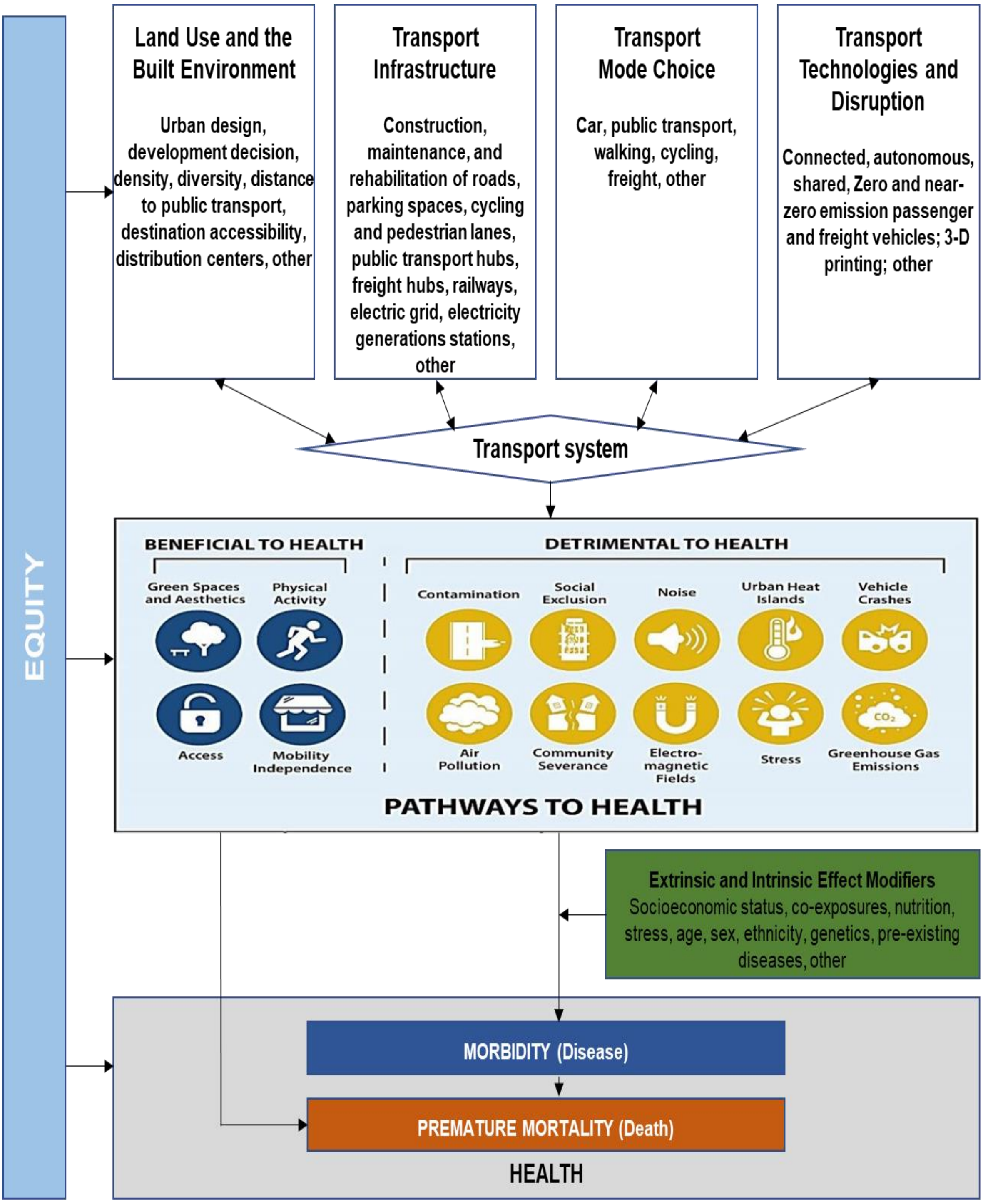

Figure 2.2 Transport and health conceptual model

Source: Adapted from Khreis et al. (2019)

More generally, Menges & Boltze (2020) develop a framework that shows the relationship between urban form, transport and health impacts, as shown in Figure 2.3.

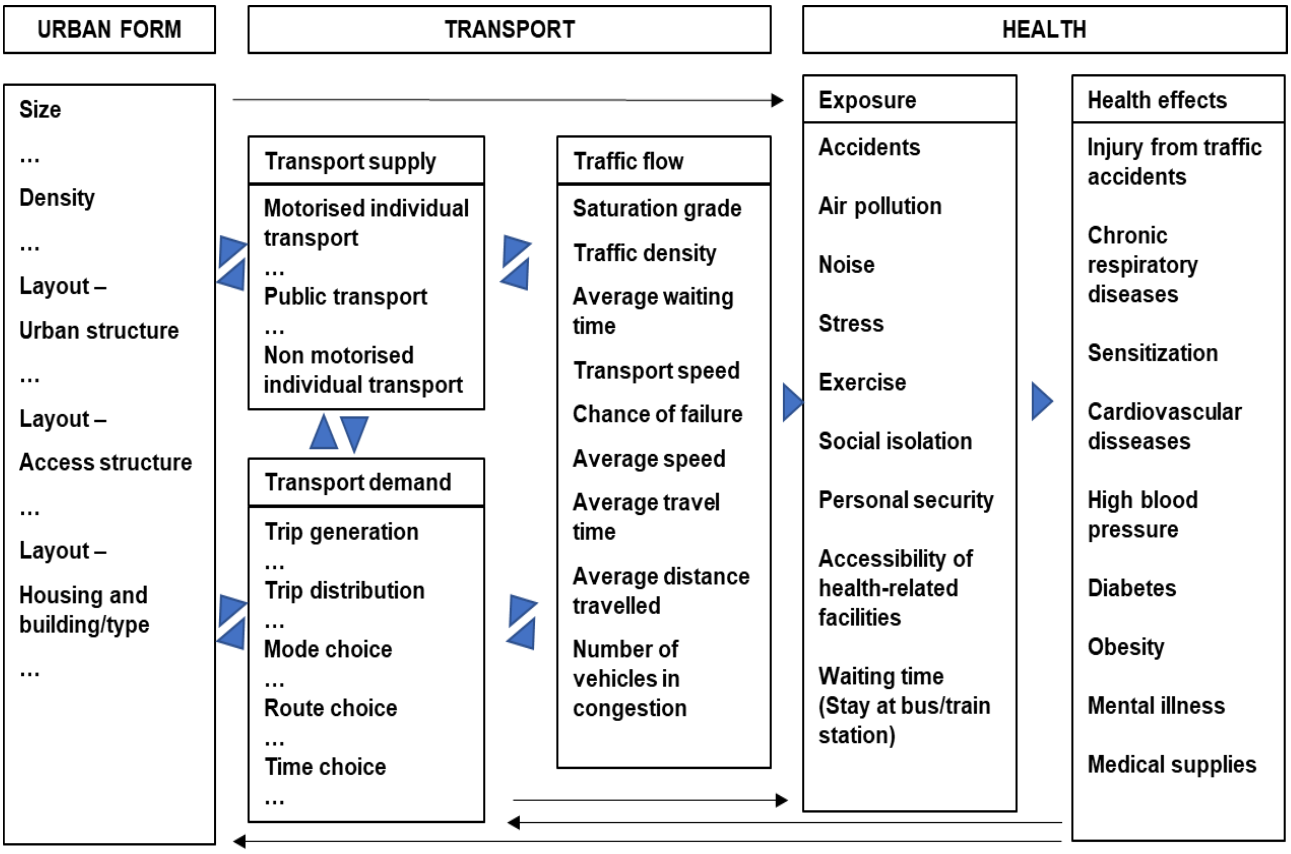

Figure 2.3 Interdependencies between urban form, transport and health impacts

Source: Adapted from Menges & Boltze (2020)

As shown in Figure 2.3, it is clear that urban form elements significantly affect transport supply, transport demand and traffic flow. Besides, Menges & Boltze (2020) analyse different transport supply and transport demand elements that influence health impacts. The authors also mention that shifting transport towards public transport and cycling has positive health impacts (Menges & Boltze 2020). The study by Menges & Boltze (2020) reveals that increasing health impact awareness influences urban and transport planning. Hence, integrating health impacts with urban and transport planning criteria plays a pivotal role in improving human health. Regarding transport demand, the authors suggest that health impacts should be considered as playing an essential role in traveller choices such as mode choice, route choice and time choice (Menges & Boltze 2020).

Traffic management influences both, transport supply and demand. This leads to changes in both supply and demand for transport. The changes in transport supply and demand lead to alteration of health impacts. Therefore, traffic management should consider health impacts as an orientation for selecting measures and developing strategies.

In comparison between two developed frameworks by Khreis et al. (2019) and Menges & Boltze 2020, Figure 2.3 sketches a more general view of interdependencies of urban form, transport system and health impacts, while Figure 2.2 just shows the relationship between the transport system and health impacts. However, Figure 2.2 provides more health exposures than Figure 2.3. In Figure 2.2, Khreis et al. (2019) determine 14 health exposures that affect human health. The authors mention that with various health exposures, there is a lack of data to determine their health effects. Thus, this study focuses on the most common health exposures which are air pollutants, noise pollution, traffic accidents, climate change and psychological stress (WHO 1998, WHO 2006, Dora et al. 2011, WHO 2012).

2.2 Existing regulations and thresholds regarding health impacts

Transport modes are crucial parts of the urban transport system which impacts human health. Transport mode users in urban areas in developing countries, especially people who travel by foot or use bicycles or motorcycles, are facing directly negative health impacts such as air pollutants, noise pollution, traffic accidents, climate change, and psychological stress. These health exposures have received much attention from scientists and scientific organisations internationally, particularly from the World Health Organisation (WHO).

2.2.1 Air pollutants

Air pollution are a significant threat to human health. The health impacts of air pollution have increased exponentially through the adverse side effects of industries, transport and several other sources. Understanding the sources of air pollutants is a way to devise suitable measures to reduce their impacts. Air pollutants are primary and secondary. Primary air pollutants are generated from a variety of sources, including road transport. Secondary air pollutants are produced by the reactions of primary pollutants in the atmosphere (WHO 2006).

The WHO (2015) reviewed all their air quality guidelines for both indoor and outdoor air pollution, and identified 32 air pollutants, as shown in Table 2.2.

Table 2.2 Air pollutants

Organic pollutants	Inorganic pollutants	Classical pollutants
Acrylonitrile	Arsenic	Nitrogen dioxide
Benzene	Asbestos	Ozone
Butadiene	Cadmium	Particulate matter
Carbon disulfide	Chromium	Sulfur dioxide
Carbon monoxide	Fluoride	
1,2-Dichloroethane	Hydrogen Sulfide	
Dichloromethane	Lead	
Formaldehyde	Manganese	
PAHs	Mercury	
PCBs	Nickel	
PCDDs/PCDFs	Platinum	
Styrene	Vanadium	
Tetrachloroethylene		
Toluene		
Trichloroethylene		
Vinyl chloride		

Source: WHO (2015)

Health effects of air pollutants

Some convincing evidence has demonstrated the relationship between emissions from transport vehicles and human health. Krzyzanowski et al. (2005) showed that conventional fuel transport modes release carbon monoxide, nitrogen oxides, benzene, black smoke, particulate matter $PM_{2.5}$, PM_{10}. These emissions cause health problems: cardiovascular and respiratory diseases, cancer and adverse birth outcomes, as shown in Table 2.3.

Table 2.3 Health effects of transport-related air pollutant

Health effects	Transport-related air pollutant
Mortality	Black smoke, Ozone, $PM_{2.5}$
Respiratory diseases (non-allergic)	Black smoke, Ozone, Nitrogen dioxide, VOCs
Respiratory diseases (non-allergic)	Ozone, Nitrogen dioxide, VOCs
Cardiovascular diseases	Black smoke
Cancer	Nitrogen dioxide, Diesel exhaust
Reproductive outcomes	Nitrogen dioxide, Carbon monoxide, Sulfur dioxide, Total suspended particles (TSP)

PM: Particulate matter; VOCs: Volatile organic compounds; CAPs: Concentrated ambient particles

Sources: Adapted from Krzyzanowski et al. (2005)

Air quality guidelines

WHO air quality guidelines are published to set standards and guidelines for air quality management (WHO 2015). The guidelines are categorised into three groups: classical pollutants, organic pollutants, and inorganic pollutants, as shown in Tables 2.4 and 2.5.

Table 2.4 WHO air quality guidelines for classical pollutants

Air Pollutants	Average Time	Time-Weighted Average
PM_{10}	Annual	20 µg/m^3
PM_{10}	24h	50 µg/m^3
$PM_{2.5}$	Annual	10 µg/m^3
$PM_{2.5}$	24h	25 µg/m^3
O_3	8h daily max	100 µg/m^3
NO_2	Annual	40 µg/m^3
NO_2	1h daily max	200 µg/m^3
SO_2	24h	20 µg/m^3
SO_2	10 minutes	500 µg/m^3

Source: WHO (2015)

Table 2.5 WHO air quality guidelines for organic pollutants and inorganic pollutants

Organic Pollutants				Inorganic pollutants			
		Averaging Time	Time-Weighted Average			Averaging Time	Time-Weighted Average
1	Acrylonitrile	n/a	No safe level	1	Arsenic	n/a	No safe level
2	Benzene	n/a	No safe level	2	Asbestos	n/a	No safe level
3	Butadiene	n/a	No safe level	3	Cadmium	Annual	5 ng/m^3
4	Carbon disulfide	24h	100 µg/m^3	4	Carbon monoxide	15 min	100 mg/m^3
		30 min	20 µg/m^3			1 h	35 mg/m^3
5	1,2-Dichloroethane	24h	0.7 µg/m^3			8 h	10 mg/m^3
6	Dichloroethane	24	3 µg/m^3			24 h	7 mg/m^3
7	Formaldehyde	30 min	100 µg/m^3	5	Chromium	n/a	No safe level
8	Polycyclic aromatic hydrocarbons	n/a	No safe level	6	Fluoride	n/a	No guideline value
9	Polychlorinated biphenyls	n/a	No guideline	7	Hydrogen sulphide	24 h	150 µg/m^3
10	Polychlorinated dibenzodioxins and dibenzofurans	n/a	No guideline			30 min	7 µg/m^3
11	Styrene	Weekly	0.26 mg/m^3	8	Lead	Annual	0.5 µg/m^3
		30 min	70 µg/m^3	9	Manganese	Annual	0.15 µg/m^3
12	Tetrachloroethylene	Annual	0.25 mg/m^3	10	Mercury	Annual	1 µg/m^3
		30 min	8 mg/m^3	11	Nickel	n/a	No safe level
13	Toluene	Weekly	0.26 mg/m^3	12	Platinum	n/a	No guideline value
		30 min	1 mg/m^3	13	Vanadium Pentoxide	24 h	1 µg/m^3
14	Trichloroethylene	n/a	No safe level				
15	Vinyl chloride	n/a	No safe level				

Source: WHO (2015)

To comprehend the impact of air quality on health, many countries have published indexes of air quality as well as recommendations on physical activities for people. These indexes are the objectives of air quality management. The indexes are also used as tools which support decision-makers in designing policies to reduce levels of air pollution.

Since PM_{10}, $PM_{2.5}$, O_3, NO_2, SO_2 exposure has health effects that are much larger and broader than other pollutants (WHO 2015), they are receiving much consideration in research. Europe, the United States of America, and some other countries published standards for PM_{10}, $PM_{2.5}$, O_3, NO_2, SO_2 exposure and recommended actions corresponding with those standards.

Europe and the US are both quite successful in health impact improvement. However, there are some differences between the two regions. The US creates air quality standards to assess pollution levels that would be a risk to public health while Europe focuses on publishing air quality limits at the level that pollution impact on human health is minimal or none (Kuklinska et al. 2015).

Over several regions, uniform policy from the council of the European Union for member states is the basis of success. By the year 2008, the European Parliament and the European Union Council published "Directive 2008/50/E.E. on ambient air quality and cleaner air for Europe". This directive is the basis for member states to update regulations and thresholds of air quality. Germany has established more stringent standards than other countries and monitors some pollutants that are not regulated by the European directive (Kuklinska et al. 2015).

Table 2.6 Immission limit values, alert thresholds and critical values in Germany

Pollutants	Limit value	Averaging time
SO_2	350 µg/m³	The emission limit value average for a full hour (24 permitted overruns in a year)
	125 µg/m³	Average immission limit value in the case of three permitted overruns in a year
	500 µg/m³	The alert threshold average for more than a full hour
NO_2	200 µg/m³	The maximum-hourly immission limit value (18 permitted overruns in a year)
	40 µg/m³	The immission limit value average over a year
	400 µg/m³	The alert threshold average for more than a full hour
PM_{10}	50 µg/m³	The average immission limit during the day (35 permitted overruns in a year)
	40 µg/m³	The average immission limit value over a year
$PM_{2.5}$	25 µg/m³	The average target over a year
	25 µg/m³	The average immission limit value to be observed over a year from 1 January 2015. the tolerance margin shall be 5 micrograms per cubic metre. From 1 January 2009, it will be reduced annually by one-seventh to 0 as at 1 January 2015
	20 µg/m³	The indicator for the average PM2.5 exposure is referred to in Section 15 May, from 1 January 2015. From 1 January 2020, a national target for reducing PM2.5exposure must be met in order to protect human health.
Lead	0.5 µg/m³	The immission limit value average over a year
Benzen	5 µg/m³	The immission limit value average over a year
CO	10 mg/m³	The emission limit value over eight-hours
O_3	120 µg/m³	The target value (25 permitted overruns in a year)
	120 µg/m³	The long-term objective as the highest eight-hour average during a day
	180 µg/m³	The information threshold as one-hour average
	240 µg/m³	The alert threshold as one-hour average
Arsenic	6 ng/m³	The target value
Cadmium	5 ng/m³	The target value
Nickel	20 ng/m³	The target value

Source: This issue is covered in 'Ordinance on Air Quality Standards and Emission Limits-39. BlmSchV' (2020)

Table 2.6 shows immission limit values, alert thresholds and critical values of air element pollutants in Germany. In more detail, the immission regulation of Germany established air quality assessment, air quality control, control plans, information to the public and reporting requirements and emission ceilings. Information to the public is an effective regulation raising residents' awareness about the health impacts of air pollution. Hence, adopting the immission regulations of Germany will bring benefits for other countries, particularly for developing countries which have a severe level of air pollution.

2.2.2 Noise pollution

There are two distinct concepts, sound and noise. Sound is a sensory perception that includes noise, music, speech etc. Sounds are made up of a complex mix of vibrations in the air of different frequencies. Frequency refers to the number of vibrations per second and it is measured in Hertz (Hz). The audible frequency range is 20-20000 Hz for humans. The sound pressure level is a measure of the intensity of the air vibrations. The human ear can detect a wide range of sound pressure levels from 10-102 Pascal (Pa). Unit of decibel (dB) represents the physical perception of the sound pressure, based on a logarithmic function and considering the human ears sensitivity level. Noise is the unwanted part of sound. The A-weighting is used to identify the relative strengths of frequency components that make up environmental noise. $L_{Aeq,T}$ is the energy average equivalent level of the A-weighted sound over a period (WHO 1995).

The noise of road vehicles is generated from the engine and the friction of vehicles with the ground and air. High-density traffic volumes and high speeds increase noise levels. Noise exposure impacts human health and causes detrimental health effects such as noise-induced hearing impairment, interference with speech communication, sleep disturbance, cardiovascular and physiological effects and mental illness (Berglund et al. 1999).

Health effects of noise pollution

Some scientific studies report that noise pollution causes hearing impairment, sleep disturbance, physiological functions, difficulties with performance, and annoyance (WHO 1998, Berglund et al. 1999).

Table 2.7 Health effects of noise level

Health effects	Noise level
Hearing Impairment	Peak sound over 140 dB for adults Peak sound over 120 dB for children The level equivalent to the average sound energy in 8 hours over 75 dB
Sleep disturbance	The equivalent sound level noise level over 30 dB
Physiological functions	The level equivalent to the average sound energy in 24 hours over 65-70 dB
Difficult with performance	Noise level in the long term
Annoyance	Noise level over 80 dB

Source: Adapted from Berglund et al. (1999)

Guidelines for community noise

The WHO published guidelines on noise and some critical health effects in Table 2.8

Table 2.8 Guideline values for community noise in specific environments

Specific environment	L_{Aeq} (dB)	Timebase (hours)	L_{Amax}, (dB)	Critical health effects
Outdoor living area	55	16	-	Serious annoyance, daytime and evening
	50	16	-	Moderate annoyance, daytime and evening
Dwelling, indoor	35	16		Speech intelligibility and moderate annoyance, daytime and evening
Industrial, commercial shopping and traffic areas, indoors and outdoors	70	24	110	Hearing Impairment

Source: WHO (1995)

In comparison with the standard of European countries and other countries, regulations of Germany are more stringent standards than in others, hence the traffic noise regulation of Germany is a good reference for developing countries. With the aim "protect the neighbourhood from harmful environmental effects caused by traffic noise, it shall be ensured during construction or substantial modification that the assessment level does not exceed one of the following emission limits" (Traffic noise protection ordinance-16th BlmSchV 2020), as shown in Table 2.9.

In addition, traffic noise protection ordinance-16th BlmSchV (2020) publishes calculations of the assessment level for roads, railways and defining acoustic characteristics for deviating railway technology and sound technology innovations.

The methods of assessment are presented in more detail. Developing countries will benefit from existing standards and the experience of Europe. It will save a lot of time for developing countries.

Table 2.9 Traffic noise thresholds of the German regulation (16. BlmSchV)

Day	Night
At hospitals, schools, spas and nursing homes	
57 dB (A)	47 dB (A)
In pure and general residential areas and small settlement areas	
59 dB (A)	49 dB (A)
In core areas, village areas and mixed areas	
64 dB (A)	54 dB (A)
In industrial areas	
69 dB (A)	59 dB (A)

Source: This issue is covered in 'Traffic noise protection ordinance-16th BlmSchV' (2020)

2.2.3 Traffic accidents

Traffic accidents have become one of the top ten causes of the global burden of diseases (WHO 2004, WHO 2014). Traffic accidents affect all age groups, but they are one of the top three causes of death for young people from 5 to 44 years old (WHO 2009). Traffic accidents have grown up along with increased motorisation. Traffic collisions mostly involve pedestrians, cyclists, and users of motorised two-wheeled vehicles, which are more numerous in low-income and middle-income countries (WHO 2009).

There are several **causes of traffic accidents**. **Vehicle speed** is an important element of the cause of injuries and deaths. Some studies demonstrate that lower vehicle speed reduces traffic injuries and deaths in towns and cities (Bunn et al. 2009, Grundy et al. 2009). **Type of vehicles** influences the risk of travellers. Generally, the collision risk of public transport users is lower than for other transport modes, while users of motorised two- and three-wheeled vehicles are at higher risk (WHO 2012). **Traffic conditions** also affect the vulnerability of transport mode users. Mixed traffic flows with pedestrians, cyclists, motorcyclists, private cars drivers and public transport vehicles cause many traffic collisions, particularly in developing countries. **Poor infrastructure** increases traffic collisions. Lack of public transport infrastructure leads to limited options for travellers. Accordingly, they have to use more private vehicles, which are the main cause of traffic accidents. **Traveller behaviour** related to mode choice and compliance with traffic regulations affects significantly the rate of traffic accidents. Drunk driving level also relates to traffic injuries and death (Mounce & Pendleton 1992). The awareness of travellers about blood alcohol level can reduce traffic accidents.

By understanding the causes of traffic accidents, policymakers and stakeholders can apply several traffic management measures and strategies to reduce the risk. For example, traffic calming, restriction of private vehicles, encouraging more public and active use, improving traffic conditions, providing more infrastructure, raising awareness, and changing traveller behaviour are effective measures to decrease injuries and deaths.

2.2.4 Greenhouse gas

Greenhouse gases raise local temperature in the world. This causes extreme weathers such as heat waves, floods, droughts, and storms. Greenhouse gases (GHG) from transport are the leading contributors to climate change, especially in developing countries (Wright & Fulton 2005).

WHO (2012) mentions three contributory factors: vehicle kilometres travelled, vehicle fuel and fuel carbon intensity which cause transport-related GHG emissions. Therefore some feasible measures are proposed such as land-use measures to reduce need for travel; mode shift from private vehicles to active transport; improved vehicle fuel efficiency; electric cars powered by renewable energy (WHO 2012). These measures should be implemented immediately in developing countries that are undergoing rapid motorisation. WHO (2012) also mentions that a monitoring system should be provided and upgraded to offer data and information for assessment.

Health effects of green-house gas emission

Khreis et al. (2016) illustrated that greenhouse gases raise local temperatures. This effect is related to premature mortality, cardiorespiratory morbidity, children's mortality and hospitalisation, heat stress, chronic diseases and preterm birth.

Several studies of transport in developing countries have been conducted in which Sperling & Salon (2002) calculated different levels of GHG emissions from different transport modes, as shown in Table 2.10.

Table 2.10 Green-house gas emission from different travel modes

	Load Factor (average occupancy)	CO_2-Equivalent Emissions grams/Passenger-Km
Car (gasoline)	2.5	130-170
Car (diesel)	2.5	85-120
Car (natural gas)	2.5	100-135
Car (electric) *	2	30-100
Scooter (two-stroke)	1.5	60-90
Scooter (four-stroke)	1.5	40-60
Minibus (gasoline)	12	50-70
Minibus (diesel)	12	40-60
Bus (diesel)	40	20-30
Bus (natural gas)	40	25-35
Bus (hydrogen fuel cell) **	40	15-25
Rail transit ***	75% full	20-50

* Ranges are due mainly to varying mixes of carbon and non-carbon energy sources (ranging from about 20-80% coal), and also the assumption that battery electric vehicles will tend to be somewhat smaller than conventional cars.
** Hydrogen is assumed to be made from natural gas
*** Assumes heavy urban rail technology (metro) powered by electricity generated from a mix of coal, natural gas, and hydropower, with high passenger use (75% of seats filled on average).

Source: Sperling & Salon (2002)

Extreme weather is a primary global health threat. While heatwaves directly affect human health causing disease and death, other indirect effects influence water and food security (Costello et al. 2009).

2.2.5 Psychological stress

Psychological stress is called the "Health Epidemic of the 21st Century" (Fink 2017)**.** Stress is caused by transport activities related to travel times, congestion, searching for parking places, and interaction with other drivers (Ding et al. 2014).

WHO (1998) illustrated some psychological stresses which are caused by transport activities. Firstly, there is posttraumatic stress from traffic accidents. Symptoms of psychological stress still remain in survivors 18 months after accidents (WHO 1998). WHO (1998) mentions that there is a lack of assessment of psychological stress after traffic accidents. Secondly, some traffic issues such as noise and congestion cause travellers' irritation and frustration or impair health, psychological adjustment and work performance (WHO 1998).

In cities of developing countries, motorised transport is rapidly leading to more congestion, longer travel times and lack of parking space which are major causes of psychological stress.

2.3 Research on health impacts and transport

There is a large number of studies on the health impacts of urban transport. The study of Vicioso et al. (2020) collected a list of 10,100 articles that linked urban transport and health. The systematic review of Fraser & Lock (2011) gathered 812 papers about cycling for transport and public health. In order to find space for this research, this section focuses on research studies on the relationship between urban transport mode choice and health impacts.

As shown in Table 2.11, the studies of health impacts have been predominantly carried out in developed countries. There is **a lack of research on health impacts in developing countries,** particularly motorcycle dependent cities. **Transport modes such as bicycle, public transport, private car and travel on foot have received more attention than motorcycles**.

There are some established study methods. First, methods measuring health impacts on vehicle users. Second, methods investigating the change of health impacts on transport mode users with shifting transport mode scenarios. Third, methods predicting the attraction of each transport mode. Travellers make decision about which transport mode they use. However, **there is lack of studies to analyse the transport mode choice behaviour of travellers which consider health impacts as an influencing factor**.

Table 2.11 Reviewing studies of health impacts and transport modes

Authors	Case study location	Transport modes	Methods	Results
Cantwell et al. (2009)	Dublin, Ireland	Public transport	Examining the level of stress and the satisfaction of comfort and reliability	Bus utility derived increases as crowding decreases and reliability increases
(De Nazelle et al. 2012)	Barcelona, Spain	On foot, bike, bus and private car	Assessing concentrations of pollutants on vehicle users	Car users are the highest polluters Pedestrians and cyclists are the lowest polluters
Rojas-Rueda et al. (2013)	Barcelona, Spain	Private cars and Public transport	Creating scenarios of car trip reduction and public transport increase	The number of cases of health problems decreases when the number of car trips reduces
Bopp et al. (2013)	The United States of America	On foot, bicycle, private car and public transport	Using logistic regression to predict the likelihood of each transport mode	Transport modes are associated with demographics and health-related factors
Xia et al. (2015)	Adelaide, South Australia	Private car and other transport modes	Estimating the amount of $PM_{2.5}$, the number of deaths and the number of disability-adjusted life years with scenario shifting transport	If the number of private cars reduces, the number of deaths per year and disability-adjusted life years will decrease
Liu et al. (2015)	Taipei, Taiwan	Subway, bus, car, and walking	Measuring exposure of $PM_{2.5}$ on four groups of users	Subway users face the lowest exposure while pedestrians face the highest exposure
Tainio et al. (2016)	Data from 1622 cities around the world	Bicycle and on foot	Estimating exposure of air pollution on active transport and comparing with the benefit of active transport	Physical activity benefits of active transport exceed negative health impacts from air pollution
Good et al. (2016)	Fort Collins, the United States	Private cars and bicycles	Examining the exposure of pollutants on private car and bicycle users on different routes	Cyclists suffer more negative impacts than private car users. Changing route can mitigate adverse effects but cause more harm for cyclists because of increased duration.
Götschi & Hadden Loh (2017)	Cities in The United States	Active transport	Evaluating health impacts by using treatment cost and value of statistical life	Treatment costs and value of statistical life reduced by half for pedestrians and cyclists
Whitfield et al. (2017)	Nashville, Tennessee, The United States	On foot and bicycle and private car	Calculating treatment cost and indirect lost productivity cost for transport users of three scenarios with increased walking and bicycling and reduced private car use	With increased active transport and decreased private car use, the treatment cost and burden of disease will be reduced
Okokon et al. (2017)	Three European cities	Bicycle, bus and car	Estimating negative health impacts caused by particulate matter, black carbon and noise on bicyclists, bus users, and private car users	Active and public transport users suffer higher negative health impacts than private car users
Thiago et al. (2017)	São Paulo cities	On foot, bicycle, private car	Using disability-adjusted life years (DALYs) and premature deaths estimate health impacts of different transport modes	The negative impacts rise with increase in the number of private vehicles. Shifting the transport mode from private transport to active and public transport promotes more health benefits

Source: Author's representation

The study results in the review table show that active transport and public transport confer more health benefits than private vehicles. **Shifting transport from private vehicles to active and**

public transport supports human health. There has been some research on policy and traffic management related to health impacts. These studies are reviewed in Table 2.12.

Table 2.12 Reviewing studies about policy and traffic management related to health impacts

Authors	Case study	Type of study	Methods	Results
Pucher & Dijkstra (2003)	The United States of America, Netherlands, Germany	Policy for active transport	Comparing fatality and injury rates of pedestrians and cyclists between the U.S., Netherlands and Germany	Pedestrians and cyclists in the Netherlands and Germany are safer than in the U.S. Effective measures from the Netherlands and Germany are lessons for the U.S. to promote walking and cycling.
(De Nazelle et al. 2011)		Policy shifting transport	Reviewing policies about health impacts that encourage active transport. Developing health impact assessment models to support decision-makers	Shifting transport policy increases both individual health benefits and public health benefits. Well-designed policies enhance positive health impacts.
Fraser & Lock (2011)	Europe	Policy to promote cycling	Evaluating the effect of the built environment on cycling	Policies about the environment and interventions are rigorously evaluated, while policies to promote cycle lane construction and socio-demographic effects are unclear.
Van Wee & Ettema (2016)		Developing a conceptual framework	Proposing a model for the association between travel behaviour and health	A framework shows the relationship between socioeconomic and demographic characteristics, physical activity, residential choice, transport behaviour and health outcomes.
Todd & Steven (2016)		Traffic management strategies	Assessing the impacts of traffic management on transport modes and crash risk	Shifting transport mode is an effective strategy for reducing traffic risks.
Smith et al. (2017)		Policy to encourage active transport	Reviewing built environment effects on physical activity and active transport	Providing more active transport infrastructure and combining strategies encourage active transport.
Vicioso et al. (2020)		Review study	Reviewing studies of association health outcomes and transport modes	Density, connectivity, access, land use mix, pedestrian infrastructure, safety, aesthetics, and green space were identified indicators that affect health impacts and transport mode choices.

Source: Author's representation

These studies of policy relate to health impacts commonly encountered in developed countries. Almost all the studies are policies for encouraging active transport by shifting transport mode.

The results confirmed that providing more active transport infrastructure attracts more active transport users. Shifting transport mode is an effective strategy for improving human health.

2.4 Conclusions

This chapter provides an overview about the health impacts of transport. Some of the key findings are presented below.

- **The concept of health impacts and terminologies relating to health impact are explained clearly to manage consistent keyword structure in this study.** These terminologies are also used as basic knowledge to develop research in transport demand modelling and transport demand management in next chapters.

- **The interdependencies of urban form, transport and health are shown.** These relationships reveal that the change of transport supply and transport demand lead to the change of health impacts. Particularly, **the change of transport mode choice behaviour plays pivotal role to change health impacts.** In this way, **transport demand management should be considered as an essential tool that influence transport mode choice behaviour.**
- In comparison to existing regulations, thresholds and guidelines of health impacts, **this study suggests that German regulations of health impacts should be applied in developing countries, particularly those facing severe adverse health impacts.**
- Reviewing studies on health impacts of transport reveals some gaps in research. Firstly, studies on urban transport and health impacts have been predominantly carried out in developed countries. **There is a lack of research on health impacts in developing countries**. Secondly, several studies assess health impacts on users regarding transport modes active transport, public transport and private vehicles. However, studies on the **health impacts of motorcycles are insufficient**. The motorcycle is the most prevalent cause of adverse health impacts in motorcycle dependent cities. Besides, motorcycle users directly interact with air pollutants, noise pollution and other adverse health impacts. Thirdly, there is limited literature which answers the **question of whether health impact awareness affects mode choice behaviour or not**. Understanding influencing factors of mode choice behaviour can help decision-makers and authorities to select suitable policies, management measures, and strategies to improve human health.

3. Transport demand modelling with consideration of health impacts

This chapter lays the groundwork for developing a transport mode choice model and its application to the case study in the following chapters. Therefore, the basic concepts and process of the transport demand model development are presented in the first and second sections. Then, each step of model development is explained. A hybrid choice model is demonstrated as the most suitable model for considering health impact factors in the transport mode choice model. Finally, based on the aim of this study, the factors to be considered in the hybrid choice model are selected.

3.1 Key definitions

Transport system and classifications

Transport is the movement of people and goods, information and energy in space. Following this definition, there are several ways to categorise a transport system. Classified by the location of the transport activity, a transport system may include water transport, air transport and land transport, including rail transport, road transport and pipelines. Categorised by the engine of transport, the system covers motorised transport and non-motorised transport. Based on the object to be transported, it includes passenger transport and freight transport. Grouping transport users introduces individual transport and public transport. Classified by the environments of transport activity, there are rural and urban areas. This study researches the relationship between urban passenger transport and health impacts. Therefore, health impacts can be used as criteria to categorise urban passenger transport, as shown in Figure 3.1.

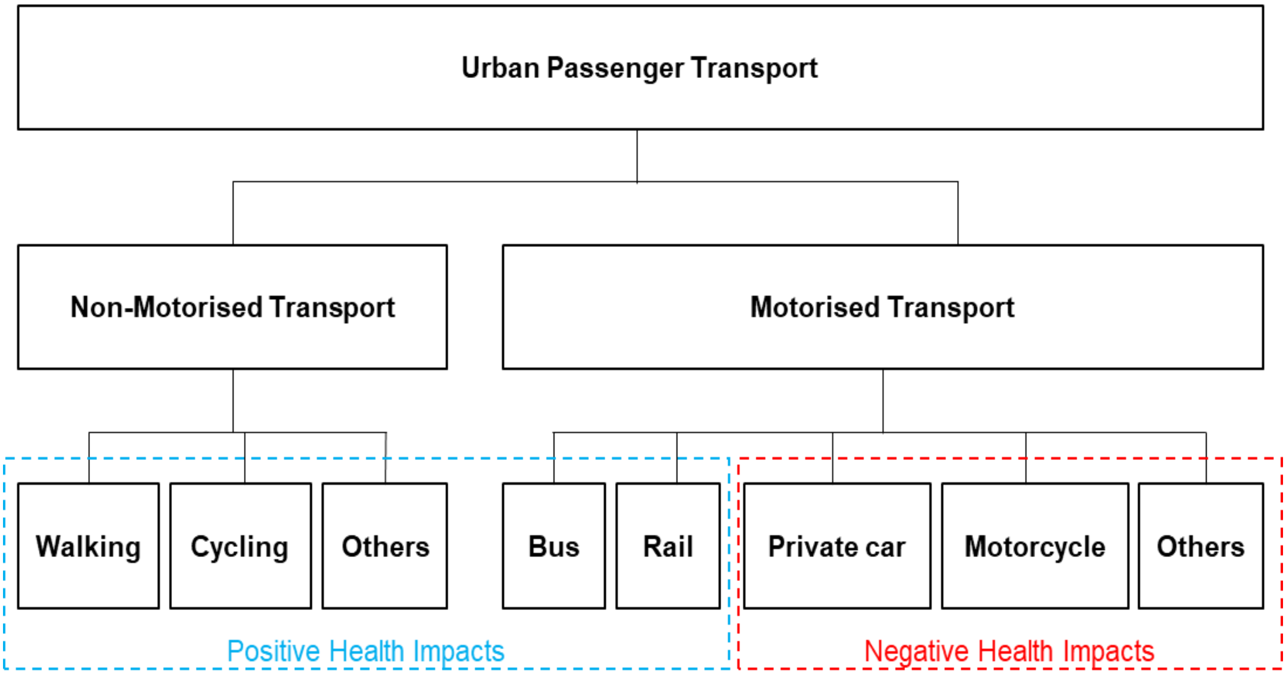

Figure 3.1 Classification of the urban passenger transport system by health impacts criteria

Source: Author's representation

As shown in Figure 3.1, non-motorised transport is in the group positive health impacts because of two reasons. First, it has zero emission. Second, non-motorised transport supports human health through physical activities. In some cases, non-motorised transport users have negative health impacts when users have contact with the polluted environment or traffic accident. However, several studies demonstrated that positive health impacts of non-motorised transport users are much higher than negative health impacts of them. Bus and rail transport is motorised transport. Therefore, they have some negative health impacts on travellers. However, It is the fact that the negative health impacts of bus and rail are trivial. More bus and rail users lead to less private vehicle users which lead to less pollution from private vehicle. Private vehicles such as private cars and motorcycles are the main cause of negative health impacts on travellers. Hence, they are classified in negative health impacts.

Transport demand

In general terms, demand is a need for something. Transport demand has a variety of meanings in research language. Ortúza & Willumsen (2011) defined the demand for transport as derived. Kanafani (1983) proposed that the need for transport stems from interactions among social and economic activities dispersed in space. In the transport research field, the concept of demand expresses the need for transport. Demand for transport is made up of transport desire, transport requirement and the ability to move.

Transport demand modelling

A model is a useful tool to represent a part of the real world. The approach to developing a transport model is derived from the main characteristics of the transport system and its associated problems. The transport model can be used to forecast demand in the future or to analyse influencing factors. To forecast demand or to analyse influencing factors, a mathematical model is developed. Mathematical models are developed based on certain theoretical statements. Depending on a particular point of view, the model considers or focuses on certain important elements. The impact factors are described in mathematical equations. The transport model can be used to forecast demand in the future or to analyse influencing factors.

Impact factors are factors that influence individual's behaviour such as explanatory variables and latent variables.

Explanatory variables are observable factors that influence traveller's behaviour such as age, gender, income, education and other socioeconomic characteristics of travellers.

Latent variables are factors that influence traveller's behaviour that they cannot be quantified in practice such as reliability, comfort etc.

Hybrid choice model is a transport demand model which incorporates explanatory variables and latent variables.

3.2 State of development in transport demand modelling

There are two ways of developing transport modelling. The first one is the aggregated approach. This approach develops models which observe an average over a group of travellers. The second *one is the disaggregated approach. This approach develops models which represent the behaviour of individuals. In this section, both approaches are discussed.*

3.2.1 Aggregated approaches

Four-step model

Aggregate modelling has undergone years of experimentation and development since the 1960s, and has produced the classic transport model (Ortúza & Willumsen 2011 p.21), as shown in Figure 3.2.

This model is developed based on the assumption that origins, O_i in a zone generate a number of trips, and destinations, D_i attract a number of trips. Hence, the study area is divided into several zones, and a transport network connecting transport zones is identified. The data is collected at base-year levels for the population in each zone. After collecting data, the four-step model is defined as follow:

- **Trip generation:** This step estimates the number of trips that are generated in or attracted to a zone. The simple model which is used is growth-factor modelling. There are three models: Growth-factor Model, Linear Regression Model, and Cross-classification Model, which can be used to predict total trips generated in and attracted to a zone (Ortúza & Willumsen 2011 p.139).
- **Trip distribution**: the trip distribution model is used to estimate the total number of trips from origin zone to destination zone. The results are shown in the origin-destination (O-D) matrix. There are three models: Growth-factor Model, Gravity Distribution Model and Entropy Model, which can be used to distribute the total number of trips (Ortúza & Willumsen 2011 p.175).

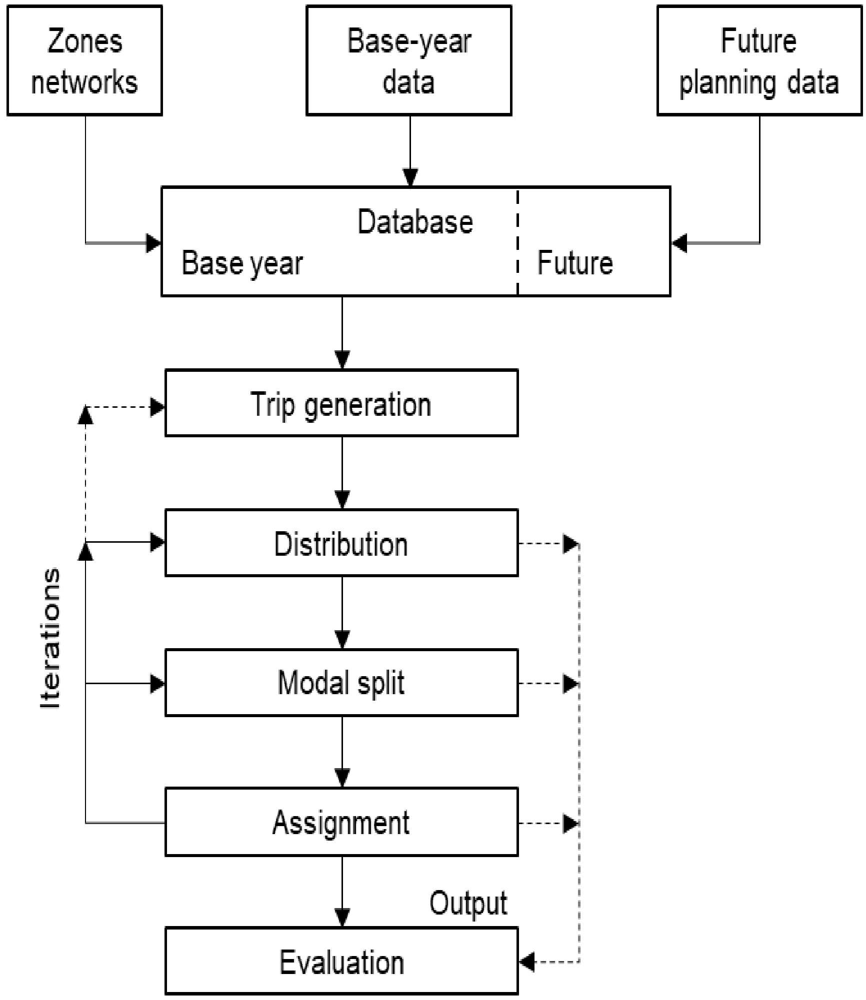

Figure 3.2 Four-step transport model

Source: Ortúza & Willumsen (2011)

- **Modal split (mode choice):** At the aggregate level, the mode choice model is used to forecast the demand for transport modes after the trip distribution step. There are some models which are available to estimate the proportion of trips by mode. The simplest model uses travel time or travel cost to calculate the proportion of trips by mode (Ortúza & Willumsen 2011 p.210). There are some more difficult models called synthetic models. Firstly, using the Entropy Model estimates trip distribution and mode choice simultaneously (Ortúza & Willumsen 2011 p.211). Secondly, the Multimodal-split Model is applied when options involve more than two transport modes. Thirdly, a direct model "*estimates demand as a multiplicative function of activity and socioeconomic variables for each zone pair and level-of-service attributes of the modes serving them*" (Ortúza & Willumsen 2011 p.220).
- **Trip assignment:** This is the step which assigns vehicles and people to the transport network. Numerous factors influence route choice, e.g. travel cost, travel time, distance, congestion. Ortúza & Willumsen (2011 p.220) classify traffic assignment methods in Table 3.1.

Table 3.1 Classification scheme for traffic assignment

		Stochastic effects included?	
		No	Yes
Single user class	No capacity restraint	All-or-nothing	Pure stochastic: Dial's, Burrell's
	With capacity restraint	Wardrop's equilibrium	Stochastic user equilibrium SUE
Multiple user classes	No capacity restraint	All-or-nothing with multiple user classes	Multiple user classes stochastic: Dial's, Burrell's
	With capacity restraint	Wardrop's equilibrium with multiple user classes	Stochastic user equilibrium with multiple user classes

Source: Ortúza & Willumsen (2011)

Land-use Transport Models

In the development of the aggregate model, Wegener (2004) presents a framework that depicts the influence of land use on transport and vice versa. The author discusses the different speeds of urban change and urban transport and demand and shows the feedback circle of land use, human activities, transport system, and accessibility. These relationships are shown in the explanation pattern (Figure 3.3).

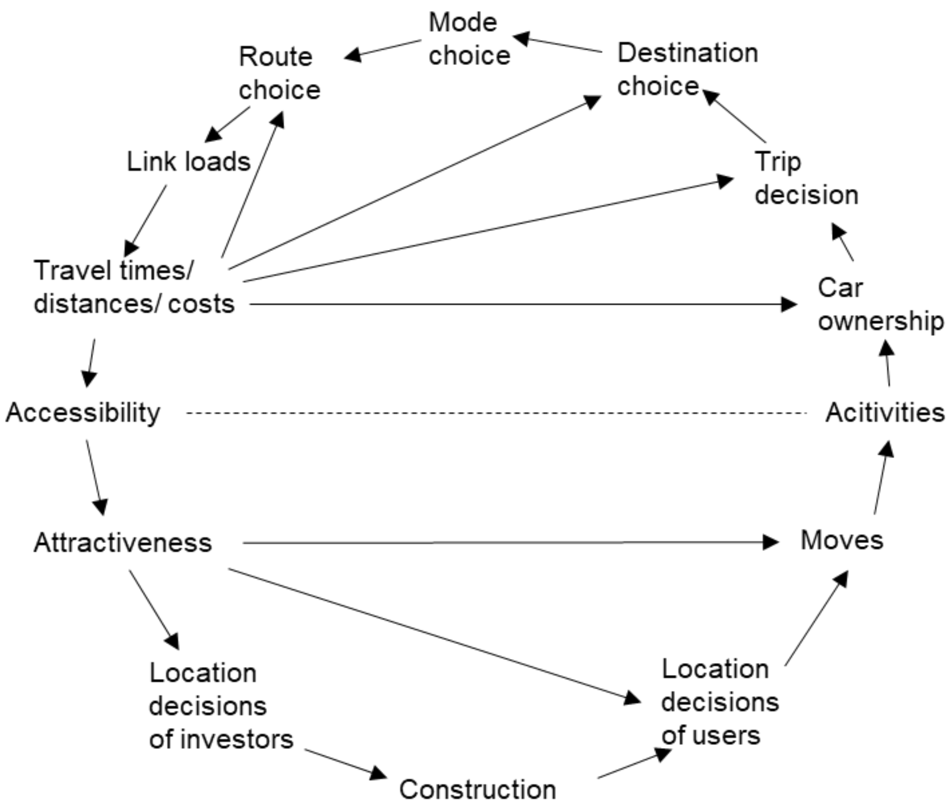

Figure 3.3 The land use transport feedback cycle

Source: Wegener (2004)

The land-use model can be applied to analyse land use planning impacts on land use development and transport, or the transport alterations' affect on other activities. However, this model requires significant effort for the data collection process. It is not amenable for private research with a limited budget.

TRANS-TOOLS

TRANS-TOOLS ("TOOLS for transport forecasting and scenario testing") is a European transport network model which covers passenger and freight as well as intermodal transport (Burgess et al. 2008). This model combines an economic model, passenger model and freight model. The outputs of the economic model are the inputs to the passenger and freight model, as shown in Figure 3.4. The steps of passenger and freight models are the same as the traditional four-step model. Components of TRANS-TOOLs model cover:

- networks for all main transport modes (road, rail, air, sea, inland waterways),
- freight and passenger transport, including interrelations between them (road congestion, mode choice),
- modal split and logistics,
- economic feedback processes related to change in accessibility and pricing,
- environmental impacts. (Korzhenevych 2012)

In fact, the TRANS-TOOLS model is used as a primary model for policy analysis at the European level (Burgess et al. 2008). This model requires a wide range of data. Hence it is feasible when the study is implemented at the regional or country level.

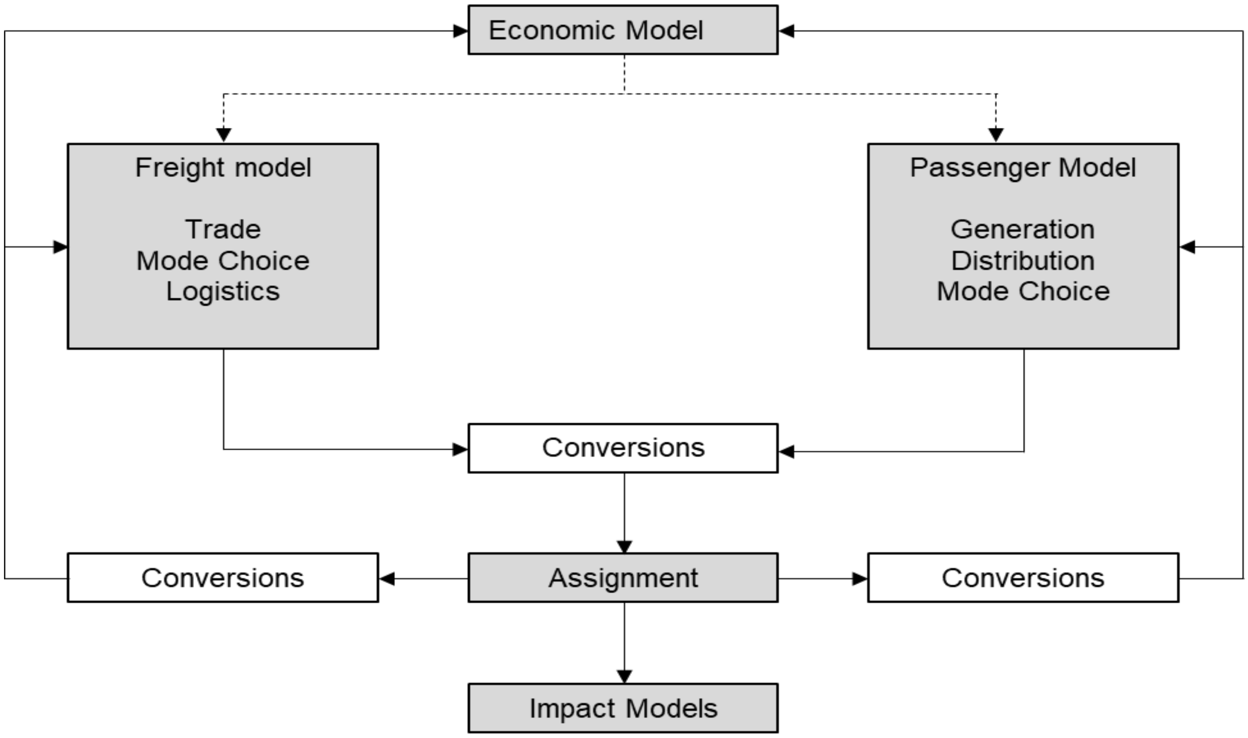

Figure 3.4 The principles of the TRANS-TOOLS model

Source: Burgess et al. (2008)

In general, the **four-step model** is used for the term "Predict and Provide". The model forecasts transport demand in the future. This supports authorities in making a plan to provide infrastructure. Based on the traditional four-step model, the **land-use transport model** is developed. This model analyses the interactions between land use planning and transport planning. This model supports policymakers in answering two main questions. The first is how land use planning influences the transport system, and the second one is how the change in transport affects land use. This model can be applied to an urban area like a compact city or a megacity. **Trans-tools model** integrates the economic model, passenger model and freight model. The core of the passenger model and freight model resembles the traditional four-step model. However, the inputs of the passenger and freight models are the outputs of the economic model above. The output of passenger and freight models extends to all of the transport modes on a huge transport network. This model supports policy analysis of the European Union applied at the European level.

In the case of passenger transport, the three models above aim at representing a traveller group's behaviour. The results of these models are the change in demand for group traveller behaviour. With the aim of describing individual behaviour, the disaggregate approach is more suitable. The disaggregate method is discussed in the next section.

3.2.2 Disaggregated approaches

Since the 1980s, the disaggregated model approach has been favoured for analysing individual behaviour compared to aggregated models. The disaggregated models are better for describing individual behaviour by using data from each traveller. Economic, psychological and geographical theories are used to develop the disaggregated models.

Discrete choice models

Discrete choice models are developed based on economic theory. Random utility maximisation (RUM) is an economic theory which is the most popular theory in application. This theory is used to create the traditional discrete choice model, including transport mode choice. The theory of RUM assumes that when an individual makes a choice from discrete alternative options, the decision-maker chooses the highest utility option (McFadden 2000), (Train & McFadden 2002), (Ortúza & Willumsen 2011). The traditional discrete choice model is defined by the RUM statement, "*The probability of individuals choosing a given option is a function of their socioeconomic characteristics and the relative attractiveness of the option*" (Ortúza & Willumsen 2011).

Based on random utility theory, there are three popular discrete choice models: the multinomial logit, nested logit, and mixed logit models. However, the traditional discrete choice models' application only considers socioeconomic factors such as income, age, gender, etc. Other factors such as psychology and awareness also affect individuals' choices; however, these are not examined in the traditional discrete choice models.

Psychological models

Psychological theories were suggested to investigate the psychological factors which influence the choice behaviour of travellers. In this regard, three psychological theories are the theory of planned behaviour, the transtheoretical model of health behaviour change and the behaviour change wheel.

The **theory of planned behaviour** described four factors attitude, subjective norms, perceived behaviour control and intentions, which influence human behaviour, as shown in Figure 3.5 (Ajzen 1991).

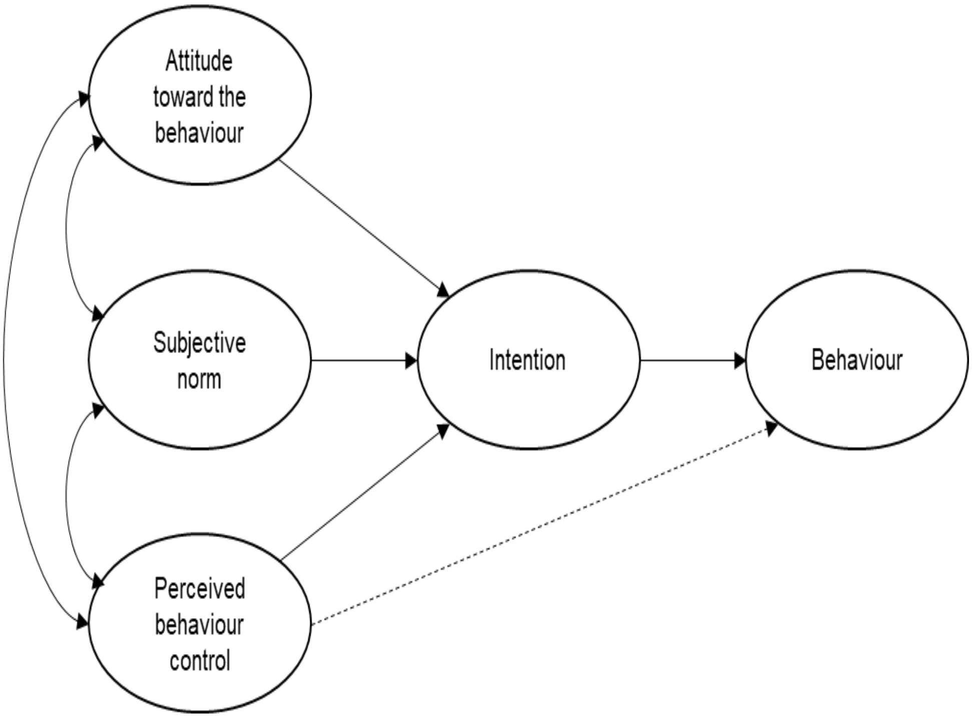

Figure 3.5 Theory of planned behaviour

Source: Ajzen (1991)

The **transtheoretical model** of health behaviour identifies six stages and ten processes that impact the behaviour of decision-makers, as shown in Figure 3.6. These stages and processes were proposed from comparative analysis of psychotherapy's theory and behaviour change (Prochaska & Velicer 1997). The first time that this model was applied was to assess the change behaviour of smokers. Then, it was applied for analysing the change of traveller's behaviour.

6 Stages of change

- Precontemplation
- Contemplation
- Preparation
- Action
- Maintenance
- Termination

10 Processes

- Consciousness Raising
- Dramatic relief
- Self-revaluation
- Environmental revaluation
- Self-liberation
- Social Liberation
- Counterconditioning
- Stimulus Control
- Contingency Management
- Helping Relationships

Figure 3.6 Transtheoretical model of health behaviour change

Source: Prochaska & Velicer (1997)

The **behaviour change wheel** uses an existing behaviour system that includes capability, opportunity and motivation impact behaviour to upgrade a new framework to analyse behaviour change, as shown in Figure 3.7 (Michie et al. 2011).

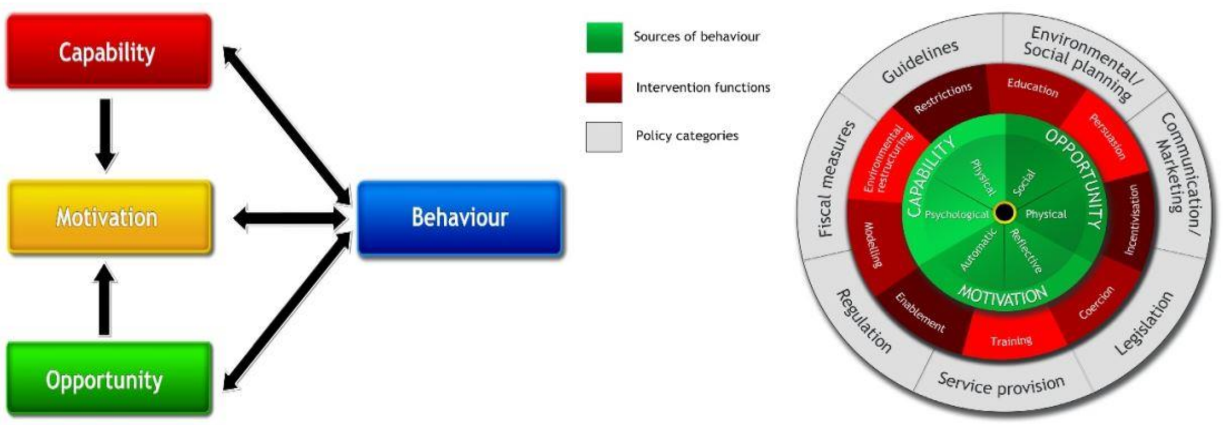

Figure 3.7 The behaviour change wheel

Source: Michie et al. (2011)

These psychological theories were initially applied to analysing the behavioural change in smokers, then transferred to examining behaviour change in travellers. However, these theories only investigated psychological factors; they did not consider the socioeconomic factors influencing travellers.

Trip-based model, tour-based model and activities-based model

In the four-step model, it is an assumption that travellers make a trip from home to work and another trip from work to home. It can be called by another name: the **trip-based model**. However, in another assumption, modellers can observe a journey from home to work then coming back home as a tour made by traveller. It can be called a **tour-based model.** Moreover, if travellers can do continuous activities in a day, for example, a person A from home to his/her office then travels to a factory and then comes to a supermarket then goes to school to pick up his/her children and comes back home. All the continuous activities of person A can be observed as an **activities-based model**. The difference between the trip-based model, tour-based model and activities-based model can be seen in Figure 3.8.

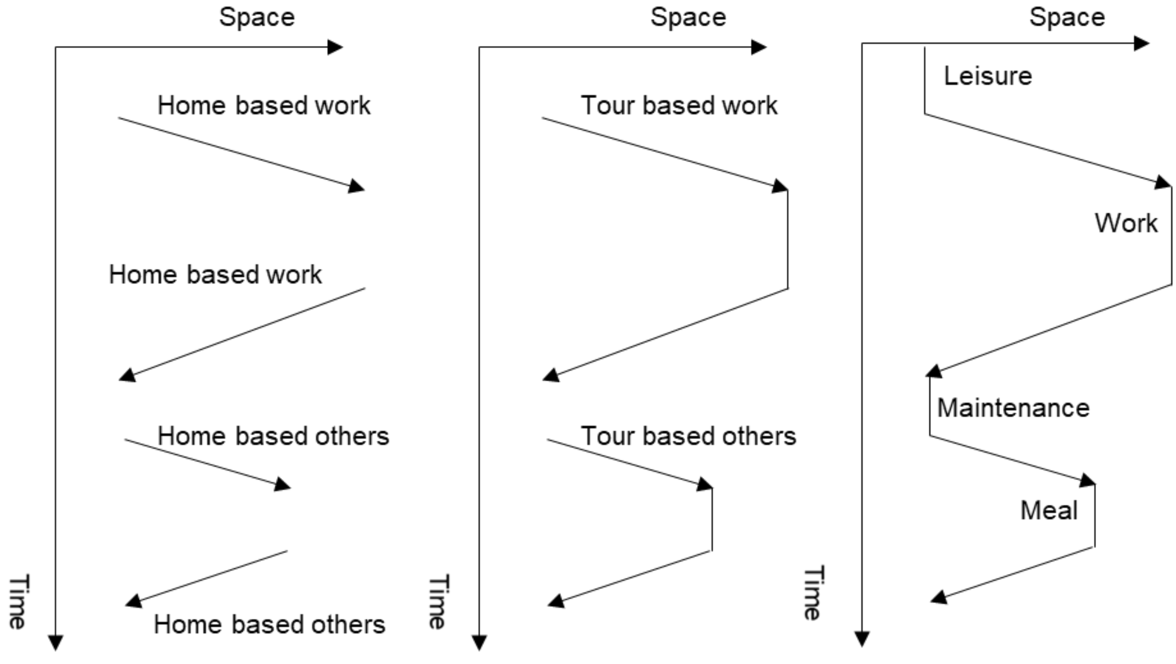

Figure 3.8 Trip-based, tour-based, and activities-base model

Adapted from: Ortúza & Willumsen (2011)

A geographical theory was proposed by Hägerstraand (1970)**.** The theory applies a time-space prism to define temporal and spatial constraints on traveller behaviour. Based on the study of Hägerstraand (1970), activities-based travel demand models were developed.

Tour-based and activities-based models can be used to analyse individual behaviour; however, data collection of activities undertaken at different locations over a period of a day or a week is not usually feasible.

To sum up, traditional discrete choice models analyse observable factors influencing mode choice behaviour. Although psychological factors and awareness also affect traveller behaviour, they are not considered in traditional discrete choice models. The psychological model only examines psychological factors, while socioeconomic factors are not studied. The tour-based and activity-based models can be used to analyse individual behaviour, but data collection for these models is not feasible.

Recently, based on RUM theory, a state-of-the-art transport demand model has been developed, known as the **hybrid choice model**. The hybrid choice model overcomes the weaknesses of the traditional discrete choice model and psychological analysis model by integrating both socioeconomic factors and psychological factors. The next section will show the hybrid model structure, function forms and variable specification and the model calibration process.

3.3 Scope of transport demand models and model development process

This section first discusses the scope of transport demand modelling, in general. Then, the scope of the transport demand model in this study is identified. Finally, a model development process is explained.

3.3.1 Scope of the transport demand models

Transport demand models are used to analyse or predict travel demands for different situations. Passenger transport demand model answers the following four questions:

1. How many trips are generated and wherefrom? (Phase 1: Generation)
2. Where are the destinations? (Phase 2: Distribution)
3. Which transport modes are chosen? (Phase 3: Mode choice)
4. Which routes are picked? (Phase 4: Route choice)

Generation

This phase aims at calculating and predicting the number of trips generated by origins (O_i) and attracted to destinations (D_i) in each zone of the study area. There are some factors which influence trip generation and attraction such as population, residential density, transport system, and socio-demographic characteristics of passengers. Trip generation and attraction can change by the time of day or by the purpose of passengers.

Distribution

This phase determines the destinations of the trips from origin zone (O_i). It generates the origin-destination (O-D) matrix. The probability of making a trip between two traffic zones depends on the resistances between them such as distance, travel time, and travel cost etc.

Mode choice

This phase determines the transport modes which are selected from origin to destination. The choice of transport mode depends on socioeconomic characteristics of users, characteristics of the journey, availability of transport modes between origin and destination, and characteristics of the transport facility.

Route choice

This phase distributes the traffic flow on different routes of the transport network with varying modes of transport. Route choice depends on several resistances such as route length, travel time, travel cost, the capacity of the route etc.

3.3.2 Identifying the scope of transport demand model in this study

Transport demand model includes four phases which are presented above. The scope of the transport demand model in this study can be explained by two main reasons regarding the transport mode choice model.

Firstly, the main focus of this study is the health impacts of transport. There is no direct correlation between trip generation and health impacts. Route choice may affect health impacts; however, the route selection will not change the health impacts on travellers for similar situations on different routes. There only effective health impacts in transport demand modelling is mode choice, which may cause different levels of impacts. To find out this relationship, a transport mode choice model is developed.

Secondly, private vehicles are the main cause of negative health impacts while public transport and active transport support human health. The change of transport mode choice can provide better travel situations for human health. To do this, influencing factors for transport mode choice behaviour need to be analysed. In this manner, transport authorities and stakeholders can understand the relation between the influencing factors and health impacts. Thus, they can select suitable policy and develop transport demand measures to change transport mode choice behaviour.

3.3.3 Model development process

Transport model development is a complex process with the aim of solving real transport problems. Therefore, the process is started from a real problem, and the final results are implemented in real life.

Basis model development process

Pfohl (2016) performs basis phases in the process of developing a model, as shown in Figure 3.9. The first phase starts with the real world's problem situation. The problem situation creates a conceptual model in which essential factors are considered. The second phase develops a mathematic model with a homomorphic illustration of the problem situation. The third phase analyses the model and finally finds the solution for the problem situation.

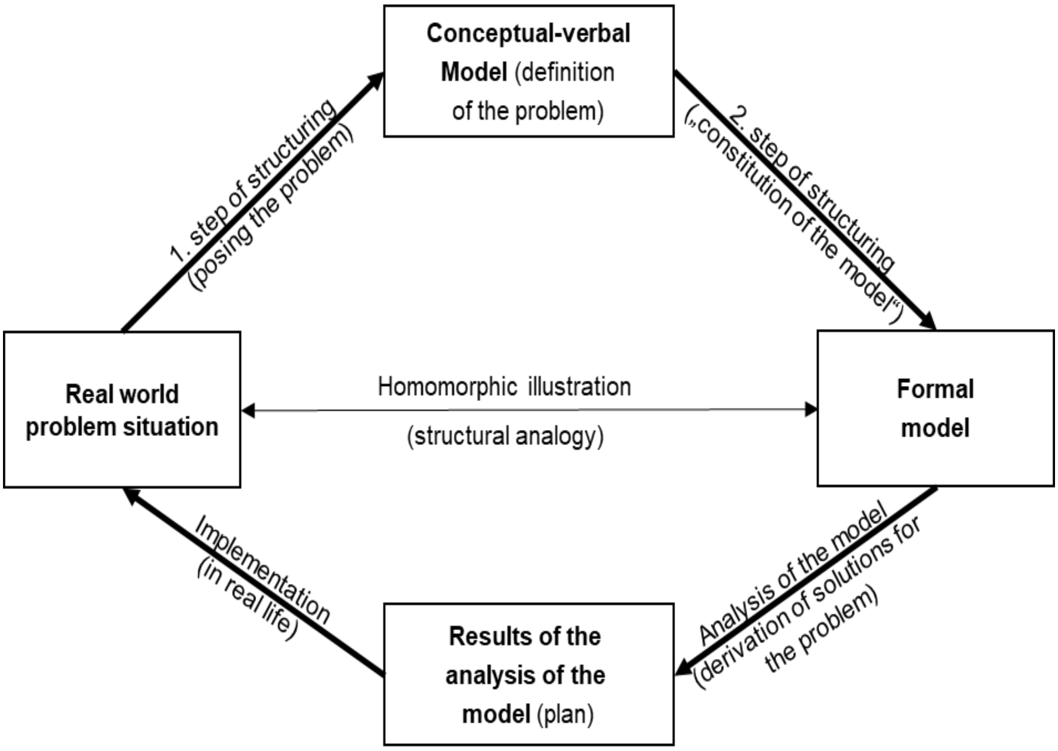

Figure 3.9 Phases of developing model to support decision making

Source: Pfohl (2016 p.262)

Transport planning models process

Ortúza & Willumsen (2011) present a framework for the transport planning process's rational decision-making, as shown in Figure 3.10.

In Figure 3.10, the first phase begins with defining the problem situation. The second phase is data collection which supports developing a model in the third phase. Phase four generates a solution for testing based on the experience of planners and forecasts variables of future demand. In the fifth phase, the model is tested with different scenarios. In the next phase, solutions are evaluated in term of finance and social assessment. Finally, the solutions are implemented.

This framework presents in more detail by adding the data collection, testing the model and evaluating solution phases. However, this framework applies to an aggregate approach that develops transport planning models. It is not to cover all of the other approaches to developing models.

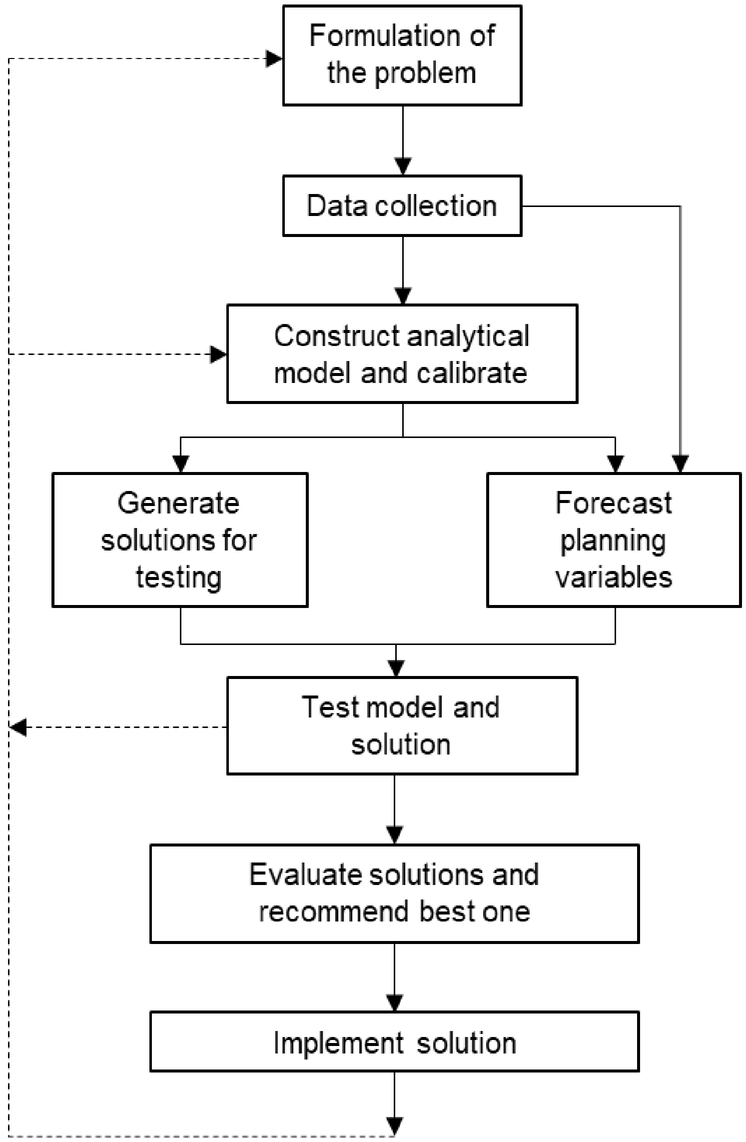

Figure 3.10 Framework for decision making with a transport planning model

Source: Ortúza & Willumsen (2011 p.23)

Based on two previous frameworks, this study proposes a novel framework that can be applied to develop transport demand models, as shown in Figure 3.11. The first phase starts with analysing the real-world problems, then the transport problems, goals and objectives are defined. Next, the modelling approach is selected, and theoretical statements are chosen which consider model specification. Then, the model structure and function form are identified. The next phase identifies the impact factors and data collection methods, and model calibration and testing are implemented. Finally, model analysis and implementation are carried out.

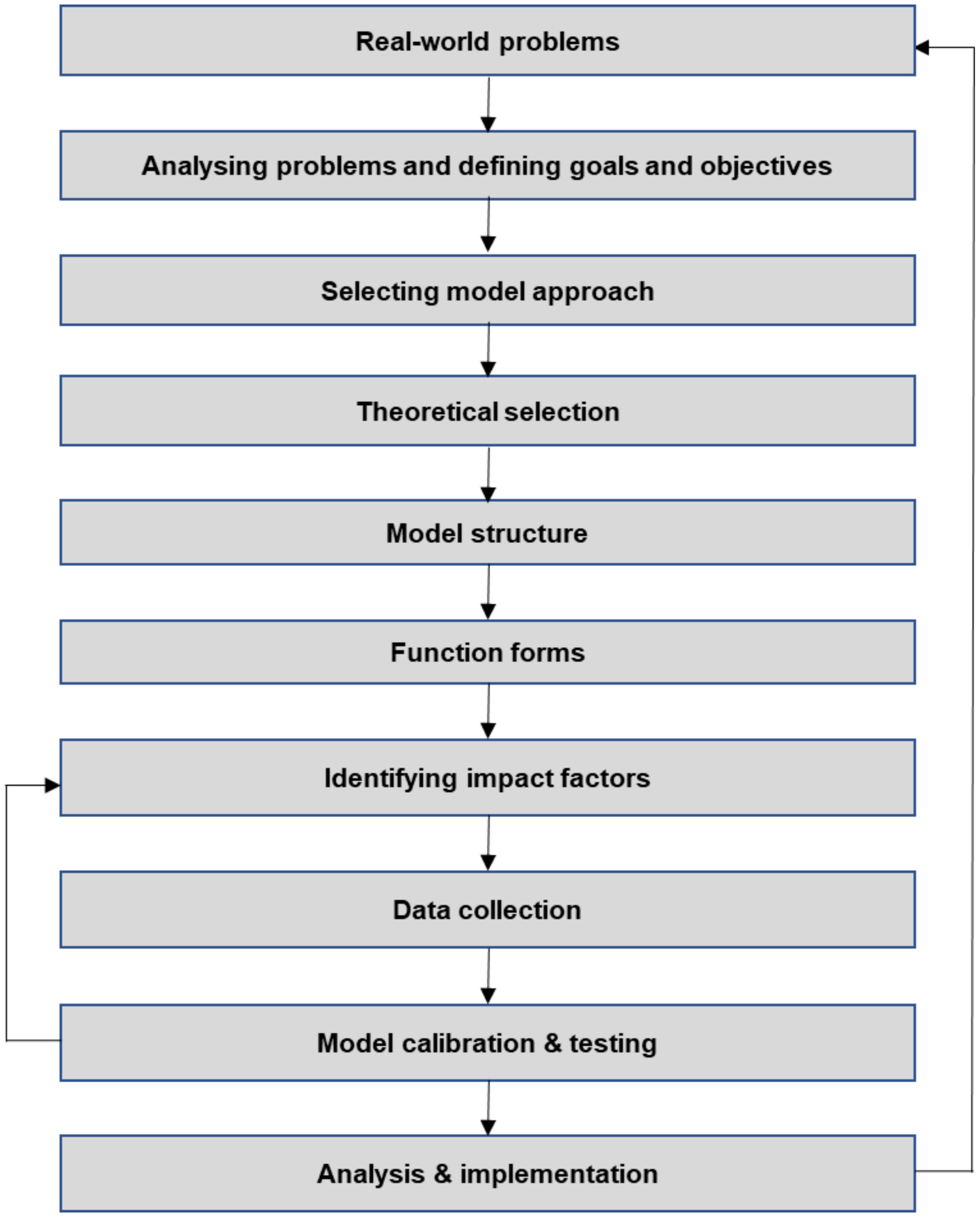

Figure 3.11 Model development process

Source: Author's representation

Real-world problems

There are several problems in the real-world which relate to transport issues such as congestion, pollution, accidents, financial deficits and health impacts. These problems need to be considered in order to improve transport systems.

Analysis problems and defining goals and objectives

Analysing transport problems supports decision-makers and planners in defining goals and objectives.

Selecting a model approach

There are two modelling approaches: aggregate and disaggregate. Hence selecting a modelling approach depends on the defined research goals and objectives. Modelling approaches also rely on the precision or accuracy of requirements, the decision-making context, the level of detail required the availability of relevant data, state of the art in modelling, the resources available for the study, the data processing requirements, the level of training and skills of the analysts and the modelling perspective and scope (Ortúza & Willumsen 2011).

Theoretical selection

Each modelling approach has several theories which can be used to develop the model. Based on the selected modelling approach, and the goals and objectives of the study, a suitable theory is chosen. Selecting a theory should consider the ability to collect data as well as computational software in the practical implementation.

Model structure

Selection of the model structure depends on variable specifications. Modellers have to choose the structure which can be used to replicate the system. Extension to methodology support presents more aspects of the system.

Function forms

Function form is identified by theoretical selection. Presenting the system more accurately needs more resources and more advanced techniques for model calibration and use. Variable specification attaches to the specification of the variables to use and how they enter a given model.

Impact factors and variables in the model

Depending on the definition of transport problems, the impact factors of the transport model are identified. From that, variables in the model are considered. Values of variables can be used to analyse transport problems and to forecast transport demand in the future.

Model calibration & testing

Model calibration, validation and use are the final steps in which parameters are chosen and tested by the goodness-of-fit measures. The value of parameters is estimated and interpreted.

Analysis and implementation

Results from step model calibration are used to analyse influencing factors. Understanding influencing factors supports decision-makers and planners in selecting effective policies, transport management measures and strategies. The final model also can be used to forecast transport demand in the future.

3.4 Developing a transport mode choice model with consideration of health impacts

In the previous chapter, it was seen that the negative health impacts of transport are an urgent issue in developing countries. To solve this issue, understanding mode choice behaviour supports decision-makers and planners in selecting effective policies or traffic management measures that change mode choice behaviour. Besides understanding how health impact factors affect transport *mode choice behaviour, this section develops a state-of-the-art mode choice model that is a hybrid choice model. This model will be applied to the case study in the next chapter.*

3.4.1 Real-world problems

Chapter 2 illustrates that urbanisation causes exponential growth of motorised transport. Motorised transport is the primary cause of negative health impacts, particularly in developing countries. Hence, carrying out more studies related to health impacts can mitigate negative health impacts in developing cities.

3.4.2 Analysing problems and defining goals and objectives

The literature review section in chapter 2 reveals some problems:

- There is a lack of research on health impacts in developing countries, particularly studies of health impacts in motorcycle dependent cities.
- In developing countries, travellers are faced with adverse health impacts. However, there have not been any studies to answer the question of whether health impact awareness influences mode choice behaviour.

The main goal of this study is to reduce negative health impacts, particularly in developing cities. In order to achieve this goal, developing a mode choice model considering health impacts awareness is an objective. The mode choice model analyses the transport mode choice behaviour of travellers. Understanding factors supports decision-makers in choosing effective management measures. These measures affect the mode choice behaviour of travellers.

3.4.3 Selecting the modelling approach

The previous phase identified the objective, which is to develop a transport model analysing individual behaviour. It was found that the disaggregate approach is suitable for realising the objective of this study.

3.4.4 Selecting theory for model development

Recently, based on random utility maximisation (RUM) theory, a state-of-the-art transport demand model has been developed, known as the hybrid choice model. The hybrid choice model overcomes the weaknesses of the traditional discrete choice model and psychological analysis model by integrating both socioeconomic factors and psychological factors. Since health impact awareness is a latent variable, the hybrid choice model is the most suitable.

3.4.5 Identifying the model structure

Traditionally, based on RUM theory, discrete choice models are applied to analyse transport mode choice behaviour. The model evaluated how socioeconomic factors (e.g., age, income, gender) affect traveller behaviour. Socio-demographic factors were named explanatory variables in the discrete choice model. However, some studies revealed that mode choice behaviour relies on observable factors as well as other factors, such as attitude or perception. Koppelman & Pas (1980) demonstrated that perceptions and feelings are the factors that affect transport mode selection. Perception and feelings are factors that are named unobservable factors.

Various studies integrate observable factors and unobservable factors in mode choice models. Ben-Akiva et al. (2002) analysed four approaches that are applied to develop the mode choice model, as shown in Figures 3.12, 3.13, 3.14, 3.15.

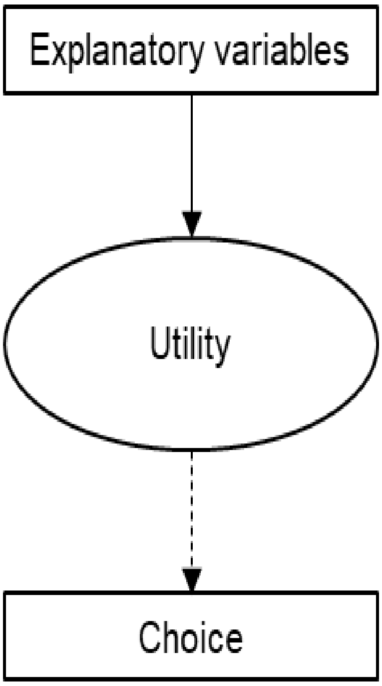

Figure 3.12 Traditional discrete choice model

Source: Ben-Akiva et al. (2002)

Figure 3.12 shows the traditional discrete choice model without latent variables. This model does not show the influence of latent variables.

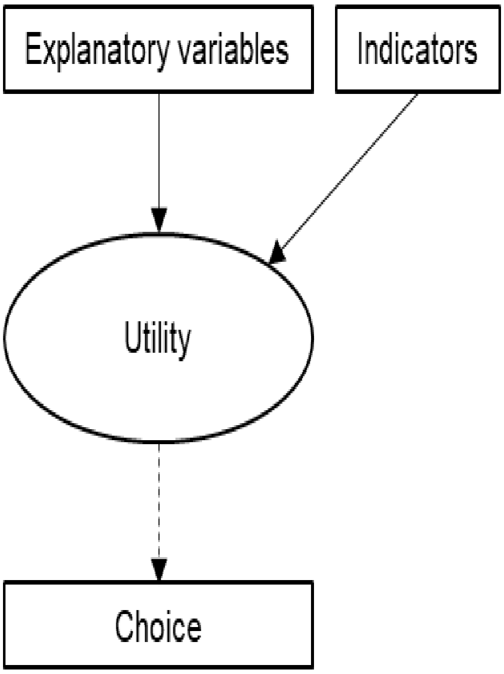

Figure 3.13 Choice model with indicators

Source: Ben-Akiva et al. (2002)

In Figure 3.13, indicators of psychological factors are integrated directly into the utility function. This model does not reveal the causal relationship between latent variables.

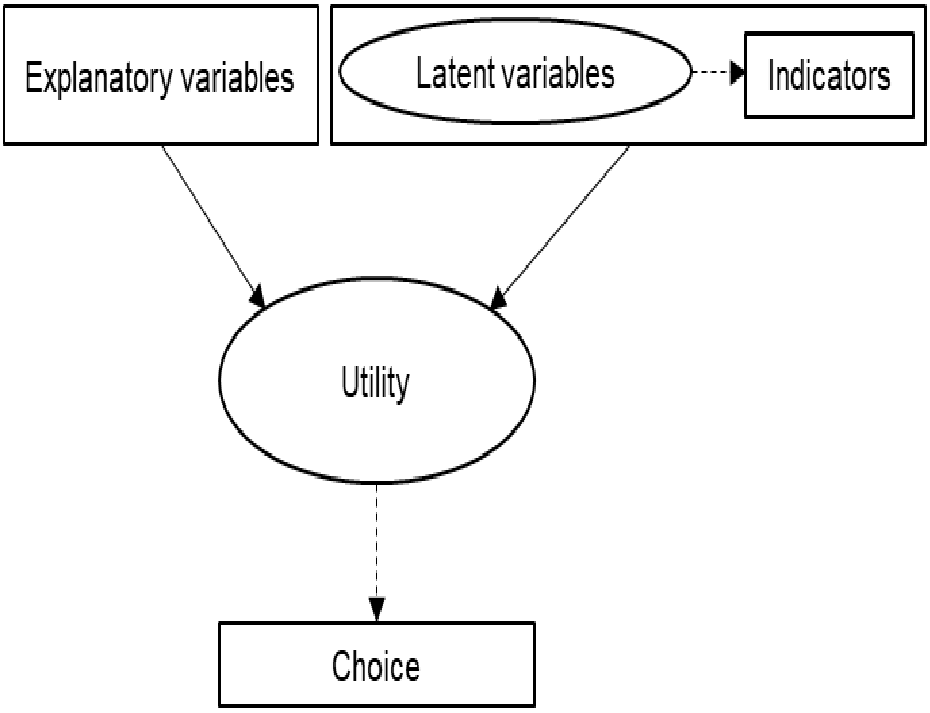

Figure 3.14 Factor analysis followed by a choice model

Source: Ben-Akiva et al. (2002)

Figure 3.14 shows two steps. Firstly, indicators perform factor analysis on latent variables, and then latent variables are incorporated in the utility function. Ben-Akiva et al. (2002) warned that the model without integration leads to measurement errors resulting in inconsistent and inefficient estimates.

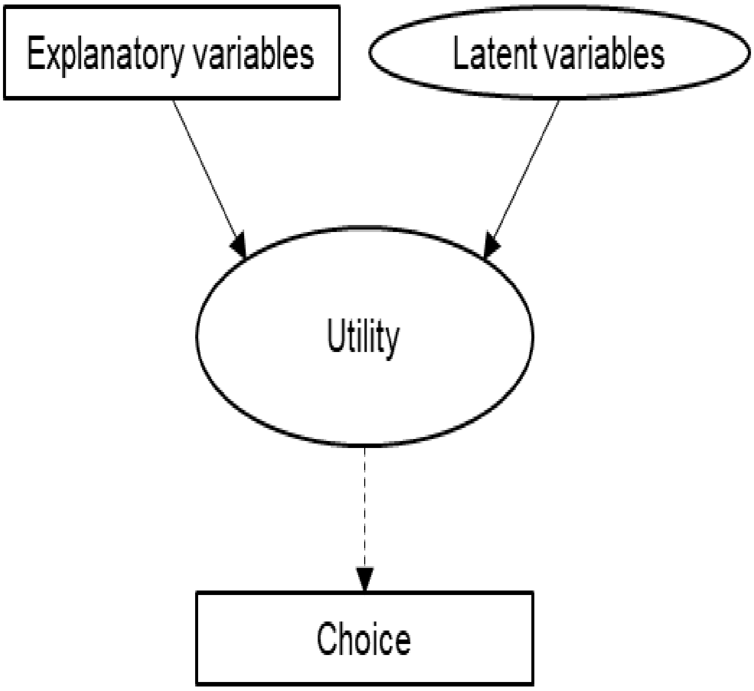

Figure 3.15 Choice model with latent attributes

Source: Ben-Akiva et al. (2002)

Figure 3.15 shows how explanatory and latent variables are integrated into the utility function without indicators. The limitation of this model is that latent variables cannot vary among individuals.

Based on theoretical analysis, Ben-Akiva et al. (2002) proposed a framework for the hybrid choice model which overcomes the deficiency of the previous frameworks, as shown in Figure 3.16

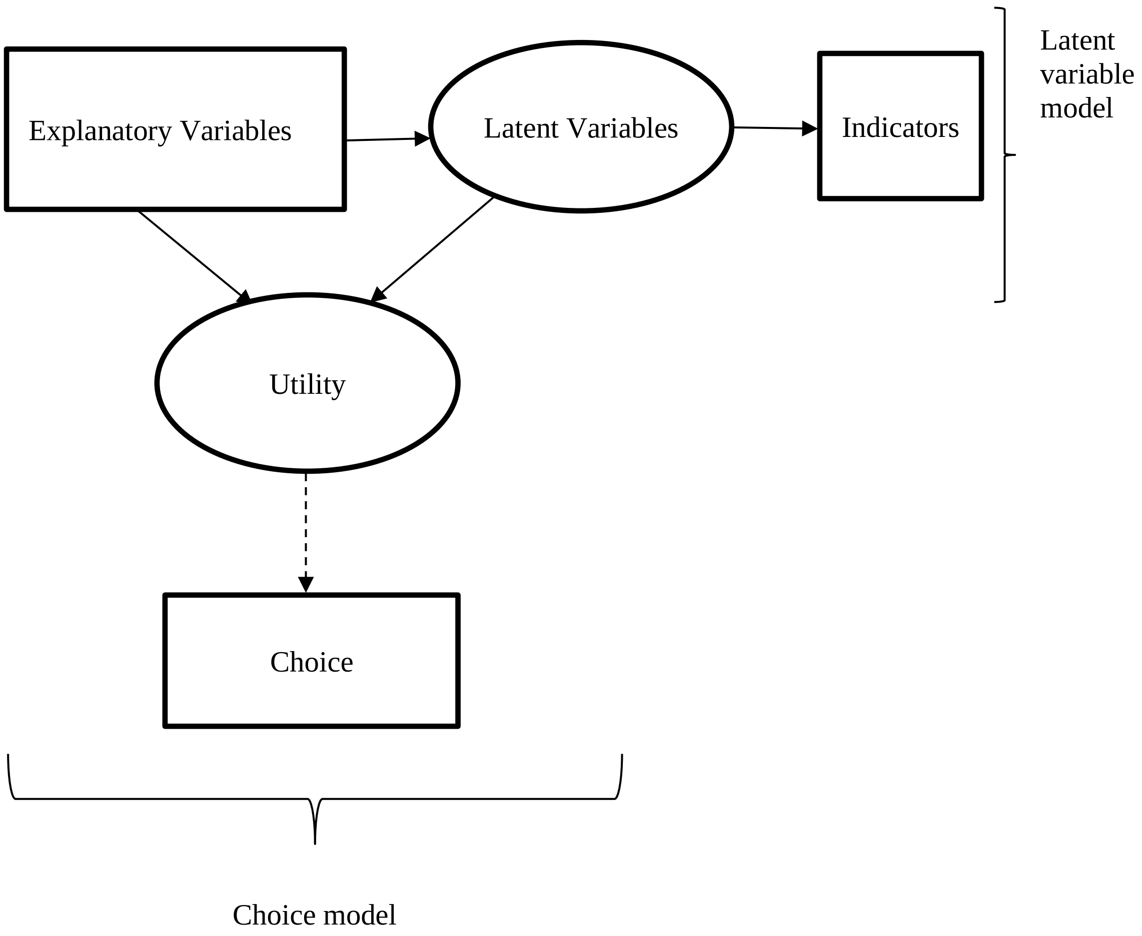

Figure 3.16 Integrated choice and latent variable model

Source: *Ben-Akiva et al. 2002*

3.4.6 Selecting the basic function form

Hybrid choice models have been proposed which consider not only the tangible attributes of the alternatives (classic explanatory variables) as in traditional models but also more intangible elements associated with users' perceptions and attitudes, expressed through latent variables (Ortúza & Willumsen 2011).

According to Ortúza & Willumsen (2011), the traditional discrete choice model was developed based on random utility theory which postulates that:

Individuals belong to a given homogeneous population Q, act rationally and possess perfect information. They always select that option which maximises their net personal utility.

There is a certain set $A=\{A_1, \ldots. A_j, \ldots, A_N\}$ of available alternatives and a set X of vectors of measured attributes of the individuals and their alternatives. A given individual q is endowed with a particular set of attributes $x \in X$ and in general, will face a choice set $A(q) \in A$.

Each option $A_j \in A$ has associated a net utility U_{jq} for individual q, and this can be represented by two parts. The first part is systematic or representative variables (V_{iq}) and the second part is random variables (ε_{iq}).

$$U_{iq} = V_{iq} + \varepsilon_{iq} \qquad (1)$$

In the traditional discrete choice model, the representative part of the utility V_{iq} is presented in Equation 2.

$$V_{iq} = \sum_k \theta_{ik}.x_{ikq} \qquad (2)$$

where the index *i* refers to an alternative, θ_{ik} are parameters to be estimated, and x_{ikq} are explanatory variables.

The hybrid choice model includes two components: a discrete choice model and a latent variable model. Hence, in systematic or representative V_{iq} latent variables and explanatory variables are incorporated, leading to a function such as:

$$V_{iq} = \sum_k \theta_{ik}.x_{ikq} + \sum_l \beta_{il}.\eta_{ilq} \qquad (3)$$

where β_{il} are parameters of latent variable η_{ilq}, *l* refers to a latent variable.

Latent variables are factors that cannot be quantified in practice, although they influence individual behaviour and perceptions (M.F Yánez et al. 2009, Raveau et al. 2010, Ortúza & Willumsen 2011). To make use of latent variables a MIMIC (Multiple Indicator Multiple Cause) model is used (Bollen 1989), where the latent variables (η_{ilq}) are explained by characteristics (s_{iqr}) from users and from the alternatives through structural equations such as Equation 4. At the same time, the latent variables explain the perception indicators (y_{ipq}) through measurement equations as shown in Equation 5.

$$\eta_{ilq} = \sum_r \alpha_{ilr}.S_{iqr} + \upsilon_{ilq} \qquad (4)$$

$$y_{ipq} = \sum_l \gamma_{ilp}.\eta_{ilq} + \zeta_{ipq} \qquad (5)$$

where index *r* refers to an explanatory variable and index *p* refers to an indicator, α_{ilr} and γ_{ilp} are parameters to be estimated, while υ_{ilq} and ζ_{ipq} are error terms. As the η_{ilq} term cannot be quantitative; both equations must be considered jointly in the parameter estimation process.

Finally, to characterise individual decisions, binary variables g_{iq} that take values according to Equation 6 have to be defined:

$$g_{iq} = \begin{cases} 1 & if\ U_{iq} \geq U_{jq}, \forall j \in A(q) \\ 0 & in\ other\ case \end{cases} \quad (6)$$

where, as usual, $A(q)$ is the set of available alternatives for individual q.

3.4.7 Identifying impact factors

There are various research studies on the incorporation of explanatory variables and latent variables in mode choice modelling. Explanatory variables or observable factors such as travel cost, travel time and socio-demographics (e.g., income, age, gender) have been considered in traditional discrete choice models to describe traveller's behaviour.

Several studies revealed that mode choice behaviour relies on observable factors as well as other factors, such as attitude or perception. Koppelman & Pas (1980) stated that perceptions and feelings are factors which affect transport mode selection. Morikawa (1989) incorporated observable factors, and latent variables, such as safety and reliability, to evaluate traveller's behaviour. Comfort and convenience were also integrated into the mode choice model as two latent variables (Morikawa et al. 2002). Johansson et al. (2006) examined mode choice with five latent variables including environmental consideration, safety, comfort, convenience and flexibility. Temme et al. (2008) utilised six latent variables which were flexibility, convenience/comfort, safety, power, hedonism and security in their mode choice model. M.F Yánez et al. (2009) considered reliability, comfort/safety and accessibility as latent variables in the mode choice model. Daziano & Ignacio (2015) examined a mode choice model with latent variables for safety, security and comfort. However, based on the purpose of the study, there were some studies that used one latent variable such as security (Daly et al. 2012) or environmental friendliness (Sottile et al. 2015). Pratim & Mallikarjuna (2017) investigated the mode choice behaviour with two latent variables, comfort and flexibility.

To examine how the health impact affects traveller behaviour, Van Wee & Ettema (2016) studied traveller behaviour and health-related attitudes, which encourage physical activity, including cycling and walking. However, the influence of the health impacts on travel mode choice behaviour was not considered in their study.

Based on the previous research, it can be concluded that a substantial number of studies investigated explanatory as well as latent variables. However, health impact awareness has not been used before as a latent variable in a mode choice model. In this study, five latent variables will be integrated with seven explanatory variables in order to analyse transport mode choice behaviour. The seven explanatory variables are gender, age, income, education, children, travel cost and travel time. The five latent variables are reliability, flexibility, comfort, convenience, health impact in which health impact is the novel factor in the hybrid choice model.

3.4.8 Data collection

Data is a tool for observing a population of interest. Since the number of individuals in the population of interest is huge, researchers do not have enough time and resources to gather all useful information. Hence, collection is limited to the useful information of a sample which can represent the whole population.

There are some potential errors in the data collection and modal development process. Two types of errors are measurement error of the data and sampling bias which can occur in the data collection process because the number of individuals in the sample is smaller than in the population. In the process of modal development, some other errors can appear, such as computational errors, specification errors, and transfer errors. Because of iterative procedures, computational errors arise. Specification errors happen because the survey form includes irrelevant variables or omits relevant variables or is designed inappropriately (Ortúza & Willumsen 2011 p.65).

To ensure a sample can represent a population, the survey process must carry out the selection of individuals independently and randomly. In order to avoid the above errors, this study divides the survey process into stages. First, based on the literature review of the model application in previous studies, variables are selected. Second, the survey form is designed, then a pilot survey is employed to test it. After the pilot survey process, if any question causes misunderstanding for the interviewer or respondents, or appears to be irrelevant, that question will be adjusted. At the next stage, surveyors choose random households in the selected area to do the survey. Finally, to examine whether the sample can be used to represent the population, statistical tests are applied. If the statistic test confirms that the sample is significantly confident, it is appropriate to represent the population.

3.4.9 Model calibration

To estimate the hybrid choice model, there are two approaches: sequential estimation and simultaneous estimation.

Sequential estimation divides into two stages. First, the parameters in the MIMIC model are estimated with explanatory variables and perception indicators. Second, results from the MIMIC model are used to calculate the value of the latent variables of each individual. Finally, the values of latent variables are used to estimate the parameters of the discrete choice model.

In sequential estimation, if a random part, ε_{iq}, are standard Gumbel distribution, then:

$$P\left(g_{iq} \middle| x_{ikq}, \eta_{ilq}, \theta_{ik},\ \beta_{il}\right) = \frac{\exp\left(\theta_{ik}.\, x_{ikq} + \beta_{il}.\eta_{ilq}\right)}{\sum_{j\epsilon A} exp(\theta_{jk}.\, x_{jkq} + \beta_{jl}.\eta_{jlq})} \qquad (7)$$

In simultaneous estimation assume that error terms ε_{iq}, v_{ilq}, ζ_{ipq} are independent. The distribution of v_{ilq} is $f_1(\eta_{ilq}|S_{iqr}, \alpha_{ilr})$, and the distribution of ζ_{ipq} is $f_2(\gamma_{ilp}|\eta_{ilq}, \gamma_{ilp})$. The choice probability is given by Equation 8.

$$P(g_{iq}, y_{ipq} | x_{ikq}, \eta_{ilq}, \theta_{ik}, \beta_{il}, \alpha_{ilr}, \gamma_{ilp}) = \int_{\eta_{ilq}} P(g_{iq} | x_{ikq}, \eta_{ilq}, \theta_{ik}, \beta_{il},). f_2(\gamma_{ilp} | \eta_{ilq}, \gamma_{ilp}). f_1(\eta_{ilq} | S_{iqr}, \alpha_{ilr}). d\eta_{ilq} \tag{8}$$

Johansson et al. (2006) and Chen & Li (2017) used sequential estimation in their research while other researchers applied simultaneous estimation (Temme et al. 2007), (Pratim & Mallikarjuna 2017). Ben-akiva et al. (2002) discuss how sequential estimation leads to measurement error and inconsistent estimates of parameters. However, the study of Raveau et al. (2010) demonstrated that both estimation methods recover the actual parameters. There are no significant differences between coefficients in application to urban mode choice. Since simultaneous estimation is more complex, this study uses the sequential evaluation method to estimate parameters.

3.4.10 Analysis and implementation

The results from the calibration step encourage modellers to analyse the impact of influencing factors. The analysis is used to implement policies, management measures and strategies. Finally, the results of the model also can be used to forecast or to analyse the changes in transport demand in the future.

3.5 Conclusions

This chapter develops a state-of-the-art demand model which considers health impact awareness as an influencing factor.

Based on the objective of the study, chapter 3 discusses key definitions of transport demand models, the state of development transport modelling and provides a general framework for developing a transport demand model. From this base, **this chapter proposes a novel model development process**.

The disaggregated approaches are suitable for analysing individual behaviour based on the review of the literature in transport demand modelling.

Existing theories for the development of a transport mode choice model are reviewed. **This step selects the most suitable way to develop a state-of-the-art model: called the hybrid choice model**.

Hybrid choice model incorporates both, explanatory variables and latent variables. Hence, hybrid choice model is feasible to consider health impact awareness as an influencing factor.

Analysing various techniques which can be used to capture latent variables in choice models illustrates that **the model structure developed by Ben-Akiva et al. (2002) is the most effective to incorporate both explanatory variables and latent variables in mode choice model.**

Reviewing previous studies on mode choice model, this chapter selects seven explanatory variables and five latent variables to analyse mode choice behaviour. **Health impact awareness is added as a novel influencing factor.**

4 Transport demand management with consideration of health impacts

This chapter clarifies the difference between two concepts, traffic management and transport demand management. The next section presents the goal, objectives, and characteristics of transport demand management. Then, the state of development in transport demand management with consideration of health impacts is discussed. The final section reviews transport demand management measures and strategies.

4.1 Traffic management and transport demand management

Economic growth boosts the rise in transport demand in both, developed and developing countries. Although long periods of investment have aimed to provide more infrastructure, transport demand has still exceeded the ability of transport to supply. The imbalance of transport demand and transport supply has created the concept of transport demand management. Transport demand management is also an effective means of solving transport problems and of reducing negative health impacts such as air and noise pollution and traffic accidents.

4.1.1 Key definitions

The definition of transport demand management is different from the definition of traffic management. According to Boltze (2014), "*Traffic management influences the supply of traffic and transport systems as well as the demand for travel and transport through a bundle of measures with the aim to optimise the positive and negative impacts of traffic and transport*". It is clear that traffic management impacts both supply and demand for traffic and transport, while transport demand management only focuses on transport demand or individual behaviour. Boltze (2014) considered demand management as an integral part of traffic management, as shown in Figure 4.1.

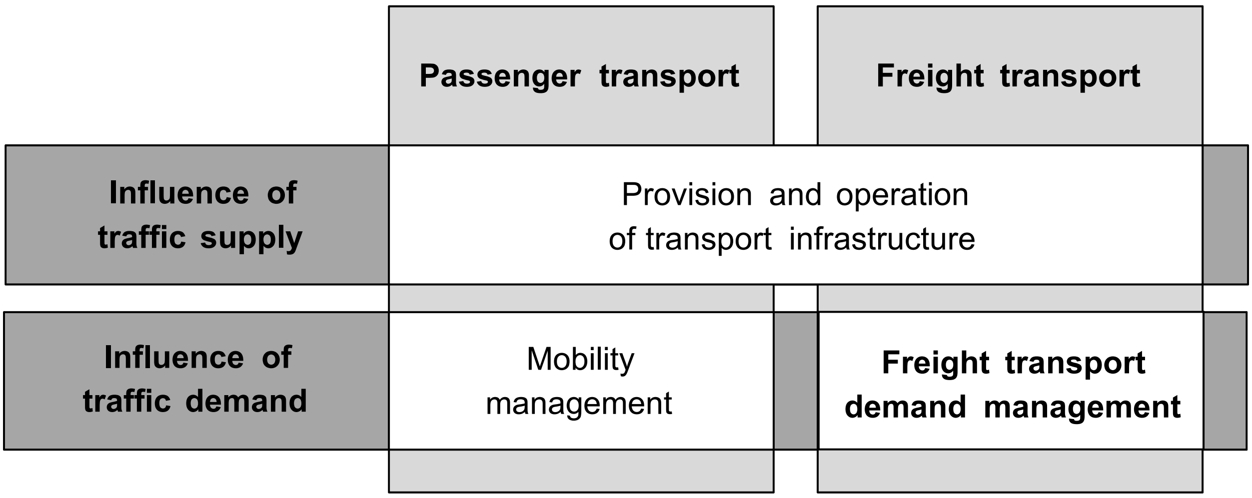

Figure 4.1 Demand management an integrated part of traffic management

Source: Boltze (2014)

Mobility management (Travel demand management) "*influences the demand for passenger transport by implementing a bundle of measures with the aim of optimising the positive and negative impacts of traffic and transport*" (Boltze 2014).

Freight transport demand management (FTDM) "*aims at influencing the demand for freight transport by implementing a bundle of measures with the aim to optimise the positive and negative impacts of traffic and transport*" (Boltze 2014).

Meyer (1999) shows that "*Transport demand management is any action or set of actions aimed at influencing people's travel behaviour in such a way that alternative mobility options are presented and, or congestion is reduced*". Broaddus et al. (2009) reasoned that "*Transport demand management can be described as a set of measures to influence traveller behaviour in order to reduce or redistribute travel demand*". These definitions reveal that transport demand management measures are used only to influence transport demand, while it does not influence transport supply.

Since transport demand management is a part of traffic management, the goals and objectives of transport demand management are also a part of the goals and objectives of traffic management.

4.1.2 Goals, objectives, and characteristics of transport demand management

Goals of transport demand management

Since transport demand management is a part of traffic management, the goals of traffic management cover the goals of transport demand management.

Khuat (2006) provided hierarchical goals and objectives which are suitable not only for developed cities but also for developing cities. As shown in Figure 4.2, the systematic goals and objectives are given from top to bottom levels. The top of the figure is the vision of the city's future. Then it shows that the development goals of a city by which to achieve a sustainable urban transport system become the highest goal for an urban transport system. Descending into the lower level involves four goals:

- To ensure mobility for all transport demand,
- To ensure safety of all traffic movements,
- To protect natural resources and the environment, and
- To improve the economy of the city and region.

In this phase, two strategic goals: "to ensure safety of all traffic movements" and "to protect natural resources and the environment" and their objectives, support human health.

Objectives of transport demand management

Broaddus et al. (2009) list three objectives of transport demand management which are:

- Reduction of traffic congestion,
- Reduction of adverse effects on the environment or public health, and
- Generation of additional revenue for public and active transport improvement.

Schwander & Law (2012) presented various objectives of transport demand management:

- Congestion reduction,
- Roadway cost savings,
- Parking cost savings,
- Consumer savings,
- Transport diversity (mobility options for non-drivers),
- Road safety,
- Energy conservation,
- Pollution reduction,
- Public health, and
- Efficient land use (smart growth).

Strategic objectives of transport and modal objectives of traffic management in Figure 4.2 cover all objectives of the two studies above.

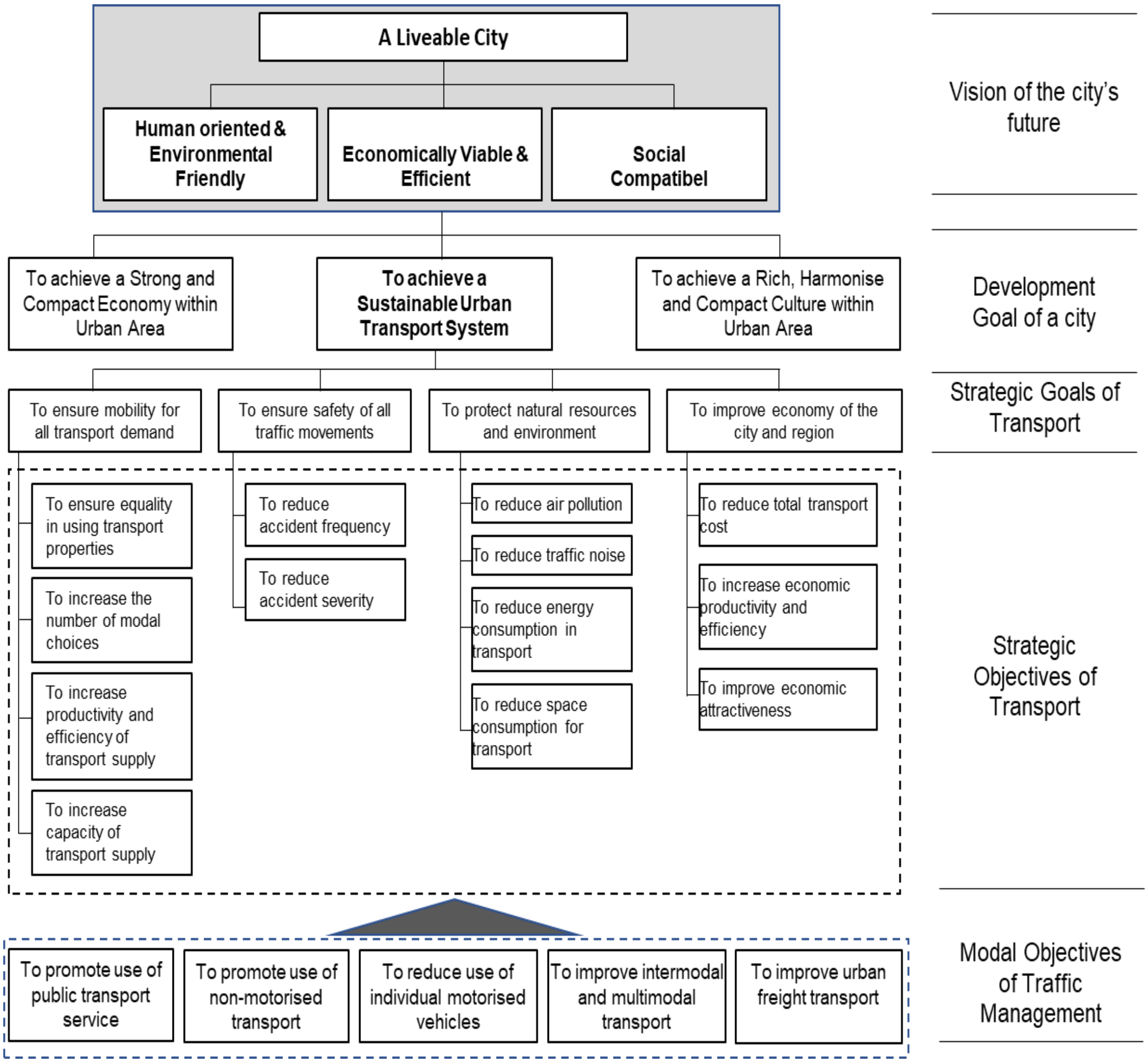

Figure 4.2 Strategic policy framework for traffic management in MDCs

Source: Khuat (2006)

At the lowest level of strategic policy framework, Khuat (2006) proposed five modal objectives of traffic management which are applied for developing cities. Mobility management is a part of these five modal objectives.

To promote use of public transport services

Public transport is the most sustainable transport for urban areas. An efficient public transport system attracts more passengers. Therefore, the number of private vehicle users decreases. The decrease in the number of private vehicles reduces traffic problems such as congestion, gas emissions, noise pollution, and traffic accidents, as well as other negative health impacts. Hence, encouraging more users to select public transport means that there is more safety, economy, and better environment. It is true that public transport is the most suitable for any city, particularly megacities.

To promote use of non-motorised transport

Non-motorised transport is environmentally friendly transport as well as a means of improving human health. However, the non-motorised transport system in developed countries has received more attention than in developing countries. The policy of using non-motorised transport from Germany, Denmark, and the Netherlands has become a valuable model for other countries in the world (Pucher & Buehler 2008). Non-motorised transport does not release pollution; however, non-motorised transport users are directly influenced by the environment and the traffic situation. Cities having bad air quality, noise pollution and other negative health impacts should become more considerate when promoting non-motorised transport.

To reduce use of individual motorised vehicle

Private vehicles are comfortable transport for individual users. However, they are the main cause of traffic problems. The domination of private car or motorcycles in many cities around the world has become a huge challenge to the goal of sustainable transport development. Reducing the use of private vehicles is an important objective for reducing traffic problems as well as reducing negative impacts on human health in urban areas.

To improve intermodal and multimodal transport

This objective improves the condition of the urban transport system. It relates to traffic signal control, urban traffic information, ring road systems, and land use. This objective belongs to transport supply in urban transport. The need for improving intermodal and multimodal transport is perpetual.

To improve urban freight transport

Urban freight transport is a component of urban transport. Improving urban freight transport is an objective of reducing traffic problems in urban areas.

The systematic goals and objectives will be used to assess the transport system of the case study of Hanoi, Vietnam. This assessment aims to find effective measures by which to reduce traffic problems and improve human health.

Characteristics of transport demand management

Meyer (1999) presents five characteristics of transport demand management:

- First, transport demand management can be implemented at specific sites or at an area-wide level. However, several actions of transport demand management can be implemented both area-wide and at specific locations.
- Second, actions of transport demand management can be employed for several travel markets with different trip purposes.
- Third, transport demand management uses different institutional mechanisms for different travel markets.
- Fourth, transport demand management can be employed for short-term or long-term programs.
- Finally, the success of transport demand management strongly depends on constituency support from various stakeholders.

These characteristics show that transport demand management can be applied flexibly, according to the study's aim.

Transport demand management with the aim of health impact improvement

Based on the strategic policy framework developed by Khuat (2006), the set of goals and objectives for health impact improvement of passenger transport are defined in Figure 4.3.

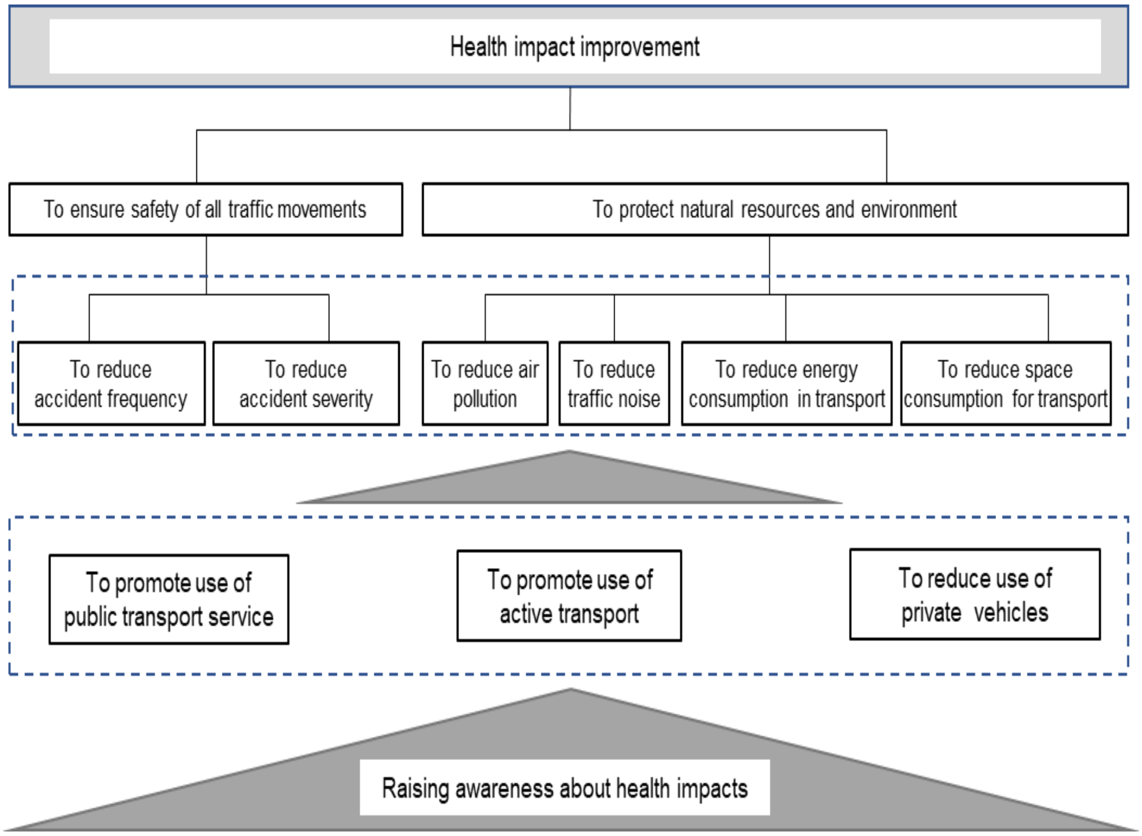

Figure 4.3 Framework for health impact improvement in passenger transport

Source: Author's representation

Health impact improvement means that increasing positive health impacts and reducing negative health impact. As can be seen in Figure 4.3, the overall goal of this study is to improve health impacts: the top level of the framework. There are two strategic goals of transport: “To ensure the safety of all traffic movements” and “To protect natural resources and the environment” which are also strategic goals of health impact improvement.

Descending to the lower level, strategic objectives are defined which relate to factors of health impact improvement such as air quality, noise level, safety and traffic congestion.

4.2 State of development in transport demand management with consideration of health impacts

In the past, demand management measures were implemented to mitigate transport problems and severe health impacts. These measures improved health impacts through reduced air pollution, reduced congestion and improved active and public transports.

In the United States, Meyer (1999) reviewed experiences in implementing transport demand management measures with environmental concerns over 20 years. Since the oil crisis of the 1970's and 1980's and the provisions of the "Clean Air Act", transport demand management has focused on reducing the use of private vehicles while encouraging the use of public transport and active transport. Transport demand strategies are implemented in numerous cities. Policymakers and practitioners have debated the efficacy of transport demand management measures. However, based on the statistical data, Meyer (1999) demonstrates that the number of trips by private vehicles, the vehicle miles travelled, reduced, while the number of public transport and non-motorised transport trips increased. The change of transport mode choice led to reduced transport problems and improved air quality indices.

In European countries, car ownership and vehicle kilometres travelled increased significantly from 1981 to 1995 (Marshall et al. 1997). Marshall et al. (1997) reviewed factors and 64 measures which were implemented to reduce the dominance of private cars. They also evaluated the effect of the measures on transport mode, the change of destination, change of time and substitution of linking trips, technology, and modifications as shown in appendix 2.

Among Asian countries, Singapore is foremost in applying the US and European experiences in transport demand management. Scientists from the US and Germany published a training document "Transportation Demand Management" for Singapore. This report provides a comprehensive transport demand management and development strategy "Push and Pull" for Singapore's case study (Broaddus et al. 2009). Singapore's success in applying the US and European methods to reduce transport problems and improve human health is of value for other developing countries.

There were several studies which focused on transport demand management. Some studies assessed the efficiency of implementation of transport demand management measures around the world. Other studies examined the facilities which support the employing of measures.

Group of studies which assess the effectiveness of transport demand management measures

ICF International (2006) used methods which estimate the emissions reduction from implementing transport demand management measures. This report used these methods to quantify the change of $PM_{2.5}$, PM_{10}, CO, NO_x, VOC_s, SO_x, NH_3 from several case studies in the US. Finally, the results analysed the impact of transport demand management strategies on reducing emission, as shown in Table 4.1.

Table 4.1 General emission impacts of transport demand management strategies

Strategies	Category of Primary Effect						General Pollutant Effect						
	Reduce VMT	Reduce vehicle trips	Shift travel time	Reduce Idling	Change speeds	Change vehicle stock of fuels	$PM_{2.5}$	PM_{10}	CO	NO_x	VOC_s	SO_x	NH_3
1. Park & Ride Facilities	√	−					↓	↓	↓	↓	↓	↓	↓
2. HOV Lanes	√	√			√		↓	↓	↓	↓	↓	↓	↓
3. Ridesharing	√	+					↓	↓	↓	↓	↓	↓	↓
4. Vanpools	√	+					↓	↓	↓	↓	↓	↓	↓
5. Bicycle/Pedestrian	√	√					↓	↓	↓	↓	↓	↓	↓
6. Transit Service Enhancement	√	√					↓*	↓*	↓	↓*	↓	↓*	↓
7. Transit marketing, Information and Amenities	√	√					↓	↓	↓	↓	↓	↓	↓
8. Transit Pricing	√	√					↓	↓	↓	↓	↓	↓	↓
9. Parking Pricing/Management	√	√					↓	↓	↓	↓	↓	↓	↓
10. Road Pricing	√	√	+				↓	↓	↓*	↓*	↓*	↓	↓
11. VMT Pricing	√	√					↓	↓	↓	↓	↓	↓	↓
12. Fuel Pricing	√	√				√	↓	↓	↓	↓	↓	↓	↓
13. Employer-based TDM Programs	√	√	+				↓	↓	↓*	↓*	↓*	↓	↓
14. Non-Employer-based TDM	√	√	+				↓	↓	↓*	↓*	↓*	↓	↓
15. Land-use	√	√			√		↓	↓	↓*	↓*	↓*	↓	↓

√=primary effect; += may be a notable effect, but not in all cases; −= may have the opposite effect, in some cases; ↓= decrease; ↓*= generally decrease, but possibility of an increase.

Source: ICF International (2006)

Sammer (2008) assessed the impact of transport demand management measures in both the short-term and long-term. In the short term, it is easy to monitor the effects of measures. Some remarkable positive outcomes are the shift from private car to environmentally friendly transport modes, reduced traffic congestion, and a change in the environment. In the long term, transport demand management relates to land use problems and the local economy. However, with the case study of the Graz and Vienna region in Austria, the author points out that it is challenging to estimate transport demand management's long-term effect.

Banister (2008) studied the relationship between congestion charging, land use and local economic impact in London's case study. The author reports a significant effect on small businesses while other businesses (retailers, finance companies) are slightly impacted. In terms of the change in land use, it is very small.

Some other assessments of transport demand measures are shown in Table 4.2.

Table 4.2 Transport management measures studies

Authors	Measures	Assessment
Meek (2008 p.165)	Park and ride	Effectiveness for reducing traffic congestion and altering private transport to public transport. Requiring combination with other measures such as restraining private vehicles and road pricing
Preston (2008 p.189)	Public transport subsidisation	Benefits for operators and public transport users Attracting more passenger to public transport
Lyons et al. (2008 p.211)	The substitution of communications for travel	Teleworking and e-shopping reduce total travel which leads to traffic problem reduction
Enock & Zhang (2008 p.233)	Travel plan	Effect on commuter traffic and promoting public transport use. Reducing congestion, air pollution.
Saleh et al. (2008 p.135)	Variable message signs provide information for driver	Reduction in accident severities Increase accident rates

Source: Author's representation

York Bigazzi & Rouleau (2017) assessed the efficiency of traffic management strategies (TMS) for improving urban air quality and health impacts. Since transport demand management (TDM) is a part of TMS, some TDM measures were evaluated in this study. Authors indicated that road/congestion pricing and low emission zones in European countries are successful in reducing air pollution; however, these measures have not been employed in North America (York Bigazzi & Rouleau 2017). The lessons from the successes in European cities relate to public acceptance and marketing strategies.

Group of studies relating to pricing measures.

Potter (2008) analysed purchase, circulation and fuel taxation measures which were employed in several European countries. Potter (2008, p.13) reveals that purchase and circulation taxes influence travellers' vehicle choices. Travellers change from less environmentally friendly cars to more environmentally friendly cars (low carbon engines or hybrids cars). This leads to a reduction of emissions in the long term; however, it does not change the number of private vehicles in use. It is only fuel tax, parking fees and road use fees that significantly impact private vehicle use.

Gillen (2008, p.49) studied the Intelligent Transport System (ITS) which is used for charging road use fees. The author shows five issues of employing ITS:

- pricing scheme (where, when and the amount to toll),
- toll infrastructure (How to toll and how should the infrastructure be managed),
- public policy (how to spend the toll revenues and design transport alternatives),
- public acceptance (how to garner support and overcome resistance from the public)
- technology (how technology can be used to improve effectiveness and efficiency).

Gillen (2008) also compared the ITS equipment in several case studies in Europe, the US and Singapore. In summary, Gillen (2008, p.49) argues that ITS's employment costs should be considered in other actual case studies.

Button & Vega (2008, p.29) present an economic theory supporting road user charging. The authors also indicate that modern technology could decrease barriers when implementing measured road user charging. They collected data from several case studies and assessed the impact of road user charging as one of a number of transport demand management measures, as shown in Table 4.3.

Table 4.3 Impacts of road user charging measures

City	Traffic effects	Congestion effects	Public transport effects
Singapore, 1975-1988	-44%; -31% by 1988	Average speed increased from 19 to 36 km/h	Modal shift, from 33% to 46% trips to work by city bus, 69% in 1983
Trondheim, 1991	-10%	n.a.	+7% city bus patronage
Singapore, 1988	-10% to -15%	Optimized road usage, 20 to 30 km/h roads, 45 to 65 km/h expressways	Slight shift to city bus
Rome, 2001	-20%	n.a.	+6%
London, 2003	-18% 2003 vs 2002	-30%. 1.6 min/km typical delay 2003, 2004 versus 2002 (2.3 min/km)	+18% during peak hours bus patronage 2003, +12% in 2004
London 2005	Small net reductions -4% 2005/2006	-22%. 1.8 min/km typical delay	Bus patronage steady
Stockholm, 2006	-30% 2006 versus 2004	-30% to -50% journey time	+6%

Source: Button & Vega (2008, p.29)

Saleh & Sammer (2009) mention that recently, pricing measures have received much attention worldwide. There are some reasons why pricing measures are popular:

- The failure of non-pricing measures.
- Technology which supports pricing system is feasible.
- Governments of several cities worldwide have greater interest in and willingness to implement pricing measures because of the effectiveness of the measures.
- Revenue from the implementation of pricing measures enhances the transport investment budget of the cities.

4.3 Transport demand management measures and strategies

Historically, several measures and strategies in transport policy influenced transport demand. However, they were not termed transport demand management (Meyer 1999). In the initial period, strategies and measures of traffic management were implemented. These actions affected both transport supply and transport demand. The requirements of effective transport system improvement through less costly actions promoted traffic management techniques which focus on transport demand. In general, it is confirmed that traffic management is the genesis of transport demand management (Meyer 1999).

4.3.1 Transport demand management (TDM) measures

The term "Measure" is defined in daily language in this context as a way of achieving something, or a method for dealing with a situation. It means that transport demand management measures are the ways to achieve the goals and objectives or the methods for dealing with transport situations.

It is possible to categorise transport modes: public transport, non-motorised transport, individual motorised vehicles, multimodal and intermodal transport, and freight transport. These traffic management measures are also classified as shown in Table 4.4.

Table 4.4 Classification of traffic management measures by transport modes

Transport modes measures	Traffic management measures
Public transport	Economic or Preferential Incentives for Public Transport
	Network Improvement
	Scheduling Improvement
	Accessibility Improvement
	Personalised Para-transit Services
	Right of Way Prioritisation
	Disaster Traffic Priority Assignment
	Disaster Transport Services
	Information Services
	Management Centre
	Inter-state Transport Operation
Non-motorised Transport	Establishment of Pedestrian Routes & Facilities
	Establishment of Bicycle Routes & Facilities
	Establishment of Automobile Restricted Zones
Individual motorised vehicles	Carpooling & other Ride Sharing Programs
	Car Rental Services
	Fuel and Vehicle Taxes
	Special Traffic Rules Enforcement
	Vehicle Improvements
	Automobile Roadway Repair Service
Multimodal and Intermodal transport	Road Network Control (Diversion Routes Establishment)
	Road Network Control (Access and Parking Restrictions)
	Road Network Control (HOV lanes Establishment)
	Road Network Control (Speed Management)
	Park & Ride Facilities
	Park and Ride Shared Facilities
	Alternate Trip Schedules & Trip Substitutions
	Interoperable & Multi-functional Transport
	Multimodal Integrated Time Scheduling/Connection Matching
	Trip Chaining/multipurpose Tours
	HOV Economic or Preferential Incentives
	Improvement of Junction Control
	Improvement of Traffic Signal Control
	Land Use Ordinances
	Traffic & Disaster Information Updates
	Work Zone Coordination & Management Centre
Freight Transports	City Logistics System
	Household Goods Delivery Transport System
	Freight Traffic Operations Control

Sources: Adapted from Minhans (2008)

Based on the impact of measures, Minhans (2008) categorised management measures in three levels. These are:

- Long-term measures involve measures that influence travellers' behaviour in the long-term.
- Mid-term measures include measures that impact travellers' behaviour in the medium-term.
- Short-term measures include measures that affect travellers' behaviour in the short-term. These measures solve current traffic situations. It can be named dynamic management.

Based on adaptability, Minhans (2008) divided management measures into two groups.

- Static management measures are implemented in a place for a long time. These measures are not flexible. Therefore, they influence traffic situations in the long-term and mid-term.
- Dynamic management measures are flexible to adapt to a particular traffic situation. Boltze & Fornauf (2013) developed a method involving dynamic traffic management strategies for incidents. This method is applied in many case studies in both, developed and developing countries.

Traffic management can be categorised into three components: multidisciplinary, supply of transport infrastructure and traffic operation, as shown in Table 4.5. Multidisciplinary includes groups of measures which are targeted in an overall planning process. Supply of transport infrastructure involves groups of measures that provide the range of transport equipment. Traffic operations comprise groups of measures which directly influence mobility. These measures can be implemented in the short term without expenditure on infrastructure. Specific measures are performed in Appendix 1.

Table 4.5 Components of traffic management

Components	Group of measures
Multidisciplinary	Land-use planning
	Agreements on use
	Marketing and awareness raising
	Measures in the political and legal framework
Supply of transport infrastructure	Facilities for public transport
	Facilities for individual transport
	Facilities for pedestrians and cyclists
	Other traffic facilities
Traffic operations	Financial and administrative measures for road traffic
	Collective information and collective control of road traffic
	Individual information and individual control of vehicles while driving
	Management of public transport
	Freight and fleet management
	Organisation of vehicle usage
	Management approaches

Source: Boltze (2016)

Marshall et al. (1997) compiled a list of 64 available transport demand measures, shown in appendix 2. These authors group the 64 measures in ten groups: Capacity management and restraint; Pricing, charging and taxation; Land use planning; Communications and technology; City and company travel policies; Physical measures; Subsidies and spending; Restrictions on access and parking; Deliveries of goods and services; Public awareness, as shown in Table 4.6.

Table 4.6 Categorisation of travel reduction measures and mechanisms

Categories of Measures	Potential mechanism					
	Switching			Substitution		
	Mode	Destination	Time	Linking trips	Technology	Modification
Capacity management and restraint	X	O		O		
Pricing, charging and taxation	X	X	X			
Land use planning: Location and access	O	X		X		
Communications and technology	X			O	X	X
City and company travel policies	X		O	O		
Physical measures: road space and priority	X			O		
Subsidies and spending (for sustainable modes)	X			O		
Restrictions on access and parking	X	X	X			
Deliveries of goods and services	O			O		X
Public awareness	X	O	O	O	O	O

Note: X = significant influence; O = some influence

Source: Marshall & Banister (2000)

Marshall & Banister (2000) assessed the potential influence of transport management groups. The possible changes are change of mode, change of destination, or change of travel time. The authors also considered substitutions, such as linking trips, technology, or modification.

Ison & Rye (2008) investigated the issues, barriers related to implementation and effectiveness of some particular transport demand management measures when applied in case studies in Europe. This study reveals experiences to overcome the barriers of implementing transport demand management measures. The issues of implementation and solutions for them are discussed in more detail in section 4.2. The list of transport demand management measures is shown in Table 4.7. This list of measures is not exhaustive; however, these measures effectively changed traveller behaviour in European countries.

Table 4.7 Groups of transport demand management measures

Type	Measures
Economic measures	Fuel Tax Road user charging Parking charges Tradable permits (Combined with regulation by quantity) Public transport subsidisation
Land use	Land use and transportation strategies such as car-free developments and location of new developments Park and Ride Facilities
Information for Travellers	Travel Information before a trip is undertaken Car Sharing
Substitution of Communications for Travel	Teleworking E-Shopping
Administrative Measures	Parking Controls Pedestrianised Zones Alternative Working Patterns

Source: Ison & Rye (2008)

Saleh & Sammer (2009) classified transport demand management measures into two groups: fiscal and non-fiscal, as shown in Table 4.8. Saleh & Sammer (2009 p.22) mention that decision-makers have greater interest in applying pricing measures to transport problems. With pricing measures, they are not only achieving their objectives but also gaining revenue. However, in order to implement pricing measures effectively, they have to raise public awareness and gain travellers' acceptance.

Table 4.8 Fiscal and non-fiscal transport demand management measures

Type	Measures
Fiscal	Parking charges Workplace parking levies Fuel taxes Vehicle excise duty Car ownership permits Public transport subsidies Priority measures for walking, cycling and road-user charging
Non-fiscal	Traffic calming Access controls and Restrictions Parking management and control Public transport improvements Road space reductions Urban traffic management and control systems Traffic bans/restrictions Travel awareness campaigns

Source: Saleh & Sammer (2009 p.22)

Broaddus et al. (2009) classify transport demand management measures in three groups: Improve mobility options, economic measures, and smart growth and land-use policies. Authors also indicate the stakeholders that need to implement, as shown in Table 4.9.

Table 4.9 Type of transport demand management measures

TDM measures	Implemented by	Key Stakeholders
Improve Mobility Options (Walking and cycling facilities; rideshare and public transport services)	City, State, National governments, transit service and shared bicycle service operators	Children and Older adults, individuals with disabilities, low income individuals
Economic Measures (financial incentives to use efficient modes)	City, State, National governments, private companies (as employers), toll road and parking facility operators	Large employers, freight hauliers, low income individuals
Smart Growth and Land use Policies (development policy to create more accessible and multi-modal communities)	City, State, National governments, developers, households (when they select a home) and businesses (When they select a building location)	Real estate developers, large employers, home buyers

Source: Broaddus et al. (2009)

Victoria Transport Institute (2020) summarises transport demand management measures in four groups: Improve transport options; Incentives to use alternative modes and reducing driving; Parking land use management; Policy and institutional reform as shown in appendix 3.

Since transport demand management is a part of traffic management, lists of traffic management measures include transport demand management measures. Therefore, transport demand management measures can be extracted from the list of traffic management measures. This study collects both traffic management measures and transport demand management measures which are applied around the world. From this, the list of feasible transport demand management measures for this study is compiled.

The list of transport demand management measures in this study is compiled in four steps.

- First, reviewing previous traffic management and transport demand management studies to collect the lists of management measures.
- Second, the traffic management measure list in this study is created by eliminating measures which overlap.
- Third, transport demand management measures are selected from traffic management measures in the second step.
- Finally, transport demand management measures for the case study are chosen to be suitable for transport demand situations.

These steps are applied to compile transport demand management measures. Tables 4.10 presents a list of measures which used for each transport mode and raising health impact awareness. Table 4.11 presents a list of measures which can support each group of measures in Table 4.10.

Table 4.10 List of TDM measures for private, public, active transport and raising awareness

	Type	Measures
Private vehicle measures	Administrative measures	Parking management
		Access control and restriction
		Monitoring
		Speed management
	Financial measures	Mobility pricing
		Road pricing, by location or time
		Oil tax and vehicle tax
		Parking charges, by location or time
		Car ownership taxation
		Pollution pricing
		Congestion Pricing
	Individual information and individual control of vehicles while driving	Dynamic individual guidance of vehicles
		Intermodal individual guidance and information systems
		Individual speed control
		Virtual chained vehicles, convoy trips
		Automatic lateral guidance of vehicles
		Car2car/Car2Infrastructure communication
		Driver assistance systems
	Organisation of vehicle usage	Vehicle emission improvements
		Carpooling & other ride sharing programs
	Facilities	Park+Ride facilities, Park+Share facilities
Public transport measures	Facilities and vehicle measures	Public transport priority
		Right of way prioritisation
		Assurance of connections
		Schedule improvement
		Passenger information systems
		Quality management
		Improving access to public transport
		Personalised para-transit services
	Financial measures	Fare arrangement
		Public transport subsidy-operators
		Public transport subsidy-individual/groups
Active transport measures	Facilities for pedestrians and cyclists	Establishment of pedestrian routes
		Establishment of bicycle routes
		Facilities for sidewalks and bicycles
		Establishment of priority zones for active transport
		Bike/Transit integration
		Public bike systems
		Walkability improvements
	Financial measures	Cycle subsidy
Raising awareness measures	Marketing and awareness raising	Raising public awareness about health impacts
		Traffic education and driver training
		Training from experts
		Media campaigns to promote walking/cycling/public transport
		Increase awareness of public transport services
	Agreements on use	Agreements to influence travel demand
		Agreements to influence modal choice
		Agreements to eliminate traffic peaks

Source: Author's representation

Table 4.11 List of supportive TDM measures

Type	Measures
Measures in the political and legal framework	Organisational measures
	Adaptation of traffic laws
	Enforcement of traffic regulations
	Alternative Work Schedules
	Flexible daily work schedules
	Company plans to encourage use of alternative modes
	Others
Collective information and collective control of road traffic	Traffic signal control
	Intersection control
	Road section control
	Lane signalling
	Network control
	Mobility service centres
	Information systems with public devices
Telecommunications measures	Teleworking/telecommuting
	Teleshopping/telebanking
	Telematics/informatics-providing information remotely
	Telematics-route planning and electronic guidance
	Telematics-VMS suggesting switching to park and ride
	Provision of non-telematics travel information

Source: Author's representation

4.3.2 Transport demand management strategies

Boltze & Fornauf (2013) define the concept of a traffic management strategy as follows: "Strategy can be defined as an action plan which includes a bundle of pre-defined measures to improve a defined initial situation".

Traffic management strategies are categorised under three approaches which are "avoid traffic", "shift traffic" and "control traffic". In the context of traffic management, strategies are developed to handle transport problems by influencing both transport supply and transport demand. Since transport demand management focuses on the demand, strategies in this study are developed to emphasise demand from travellers.

As can be seen in Figure 4.4, two approaches, 'avoid traffic' and 'shift traffic' are most strongly influencing transport demand and are more significant than the 'control traffic' approach. Particularly, the 'shift traffic' approach is demonstrated to be effective for objective improvement of health impacts in transport as shown in chapter 2. The 'avoid traffic' approach is applied towards the long-term objective, which aims to reduce the number of trips or trip lengths (vehicle-km or passenger-km). The 'shift traffic' approach aims to change departure time, change transport mode, or change destination. Shifting traffic can be applied in all short-term, mid-term or long-term scenarios.

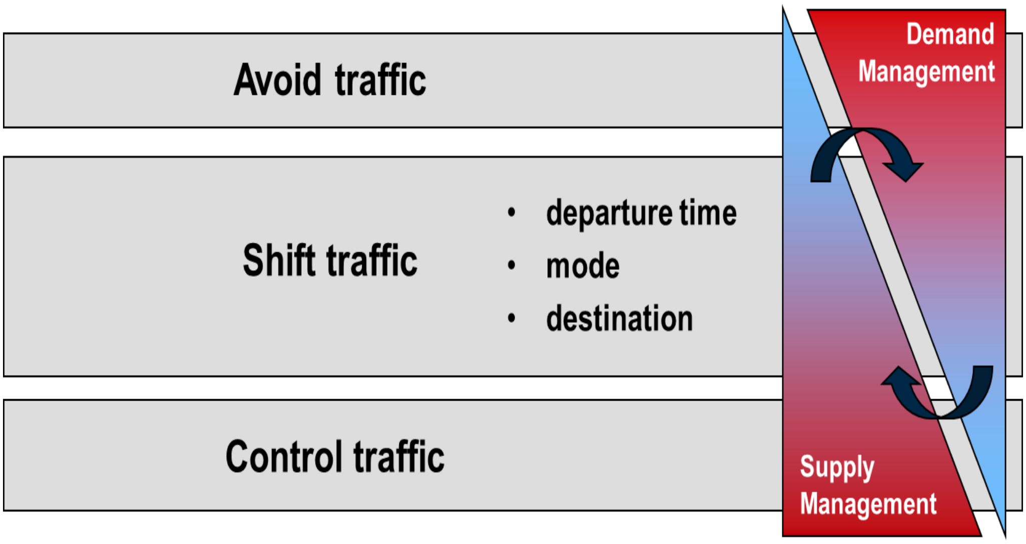

Figure 4.4 Traffic management approaches

Source: Boltze (2017)

In order to develop strategies for transport demand management, this study applies the German method, which is presented in a guideline (FGSV 2003) as well as in the further research of Boltze & Fornauf (2013).

The German method develops strategies in three steps:

- First, measures are applied to situations in the first steps, as shown in Table 4.10. Appropriate for a particular problem, a feasible transport management measure can be selected. This step is implemented based on matrix A.

Table 4.10 Feasible measures for transport problems

Matrix A			Problem category								
			Problem A	Problem B	Problem C	Problem D	Problem E	Problem F	Problem G	Problem H	....
Measure categorises	PT	Measure 1.1									
		Measure 1.2									
	IT	Measure 2.1									
		Measure 2.2									
	MT	Measure 3.1									
		Measure 3.2									
	MIT	Measure 4.1									
		Measure 4.2									

PT: Public transport, IT: Intermodal transport, MT: Multimodal Transport, MIT: Motorised individual traffic

Source: Adapted from Boltze & Fornauf (2013)

- Second, matrix B evaluates the need for supportive systems for the selected measures such as control, information, and guidance systems. These systems facilitate measures, as shown in Table 4.11.

Table 4.11 System for information, control, and guidance

Matrix B			Systems											
			Information				Control				Guidance			
			System 1.1	System 1.2	System 1.3	………	System 1.1	System 1.2	System 1.3	………	System 1.1	System 1.2	System 1.3	………
Measure categorises	PT	Measure 1.1												
		Measure 1.2												
	IT	Measure 2.1												
		Measure 2.2												
	MT	Measure 3.1												
		Measure 3.2												
	MIT	Measure 4.1												
		Measure 4.2												

PT: Public transport, IT: Intermodal transport, MT: Multimodal Transport, MIT: Motorised individual traffic

Source: Adapted from Boltze & Fornauf (2013)

- Finally, Matrix C identifies the requirements for implementation to ensure the efficiency of measures, as shown in Table 4.12. This step needs to be integrated with the preparation of the measures. Appropriate for a measure, required systems are located in a general term or at a specific place. Required systems may include facilities, the staffing requirement or a financial budget.

Table 4.12 Requirements for actions

Matrix C			Need for action								
			Requirement A	Requirement B	Requirement C	Requirement D	Requirement E	Requirement F	Requirement G	Requirement H	………
Measure categorises	PT	Measure 1.1									
		Measure 1.2									
	IT	Measure 2.1									
		Measure 2.2									
	MT	Measure 3.1									
		Measure 3.2									
	MIT	Measure 4.1									
		Measure 4.2									

PT: Public transport, IT: Intermodal transport, MT: Multimodal Transport, MIT: Motorised individual traffic

Source: Adapted from Boltze & Fornauf (2013)

The combination of problems, measures, supportive systems, and requirements creates a strategy mask, as shown in Figure 4.5. The strategy mask gives the action plan for the application. The strategy mask is a German method that is applied in several cities in both developed and developing countries around the world.

Strategy Mask

For **Situation "X"** described by

- Problem B
- Problem F

Strategy

- Measure 2.2
- Measure 4.1

Systems to be used

- System 1.1
- System 3.1
- System 3.3

Need for Action

- Requirement D
- Requirement F
- Requirement H

Figure 4.5 Sample strategy mask for situation X

Source: Adapted from Boltze & Fornauf (2013)

4.3.3 Assessment and optimisation of strategies

A method to assess management measures is presented in the study of Khuat (2006). The method uses a multi-criteria model to examine candidate measures. The result of the assessment process is selection of effective and applicable measures for a particular traffic situation. Multi-criteria assessment methods divide into five steps:

- First, selecting and classifying management measures

- Second, choosing criteria for assessment. Khuat (2006) chose two hierarchical groups of criteria effectiveness and applicability. Based on management measures' goals and objectives, criteria in two groups: effectiveness and applicability, are selected.
- Third, assessing the weight of assessment criteria. Khuat (2006) assesses the weight of criteria by using an Analytical Hierarchy Process (AHP) to conduct interviews of expert's.
- Fourth, qualitative scaling effectiveness and applicability: this step assesses the impact on a transport system toward the strategic goal and objective (Khuat 2006).
- Finally, the evaluation and selection of measures is completed.

Boltze & Fornauf (2013) show the strategy assessment process. Seven steps are shown in Figure 4.6. This method can be applied to assess transport demand management.

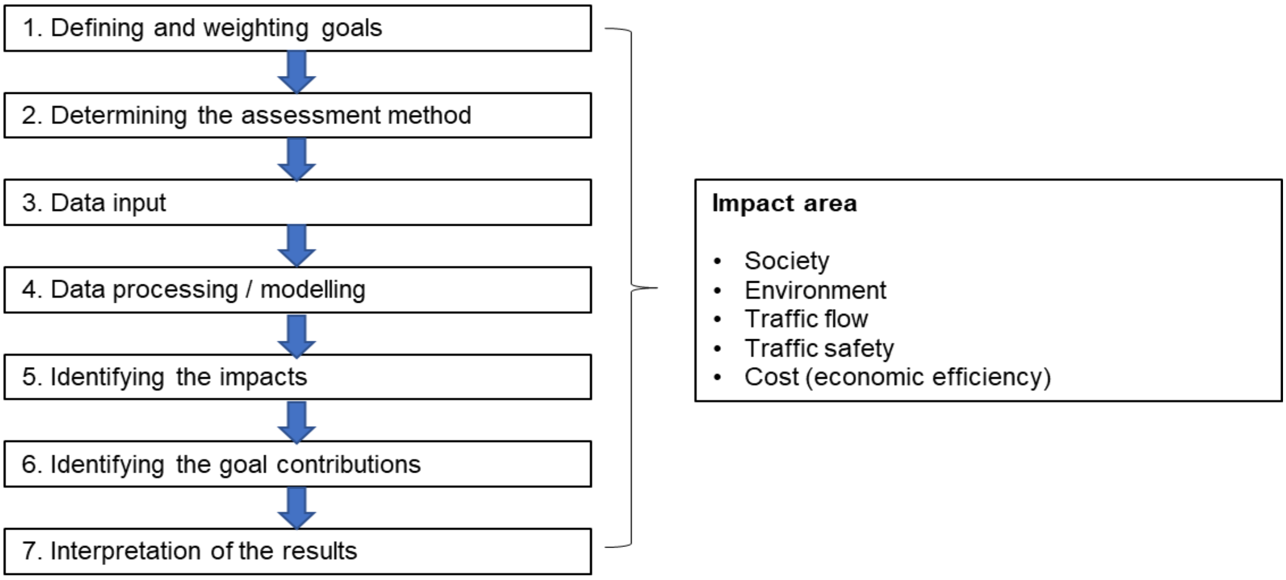

Figure 4.6 Strategy assessment process

Source: Boltze & Fornauf (2013)

The first step ensures that developed strategies comply with the goals and objectives of transport demand management. At this step, different criteria are selected to be suitable for the local conditions. Both the positive and negative effects of developed strategies are quantified, and the effectiveness of developed strategies is assessed.

The second step identifies the assessment method. Boltze & Fornauf (2013) show that the assessment method depends on the complexity of the situation.

Throughout the next steps, data is collected for the appropriate method. From the results, possible impacts of the strategy are identified.

Finally, the results are interpreted, and the expected results are determined.

4.3.4 Stakeholders in transport demand management

Each measure in the list of feasible transport demand management measures requires the responsible involvement of a stakeholder. Some actions are the national government's responsibility, while other measures may be the responsibility of local government, service providers, transport operators, or transport users. Therefore, to ensure effectiveness when implementing transport demand management measures, the combination of stakeholders plays an especially important role.

Figure 4.7 shows the stakeholders who relate to the implementation of traffic management. It is also the concern of transport demand management.

Land Authorities

Depending on the structure of the government of a country, land planning may be the responsibility of the central government, state, regional or local government. The governmental organisations decide how land planning influences aspects of transport demand, such as the total number of trips, the mode of use and the origin and the destination of trips. Policymakers also encourage or discourage transport modes in urban areas. Hence, the effectiveness of implementation of management measures significantly depends on governmental organisations.

Public transport operations

Public transport operations include companies which provide bus, train and taxi services. These operators impact on factors affecting the quality of public transport services: information, scheduling, reliability, flexibility, comfort, convenience, and health impacts. Demand management measures influence these factors which entice more users onto public transport.

Service providers

Service providers include information services, parking lots, airports, and trade exhibitions. These providers serve the needs of both transport users and operators. Hence, governments may subsidise service providers to undertake demand management measures.

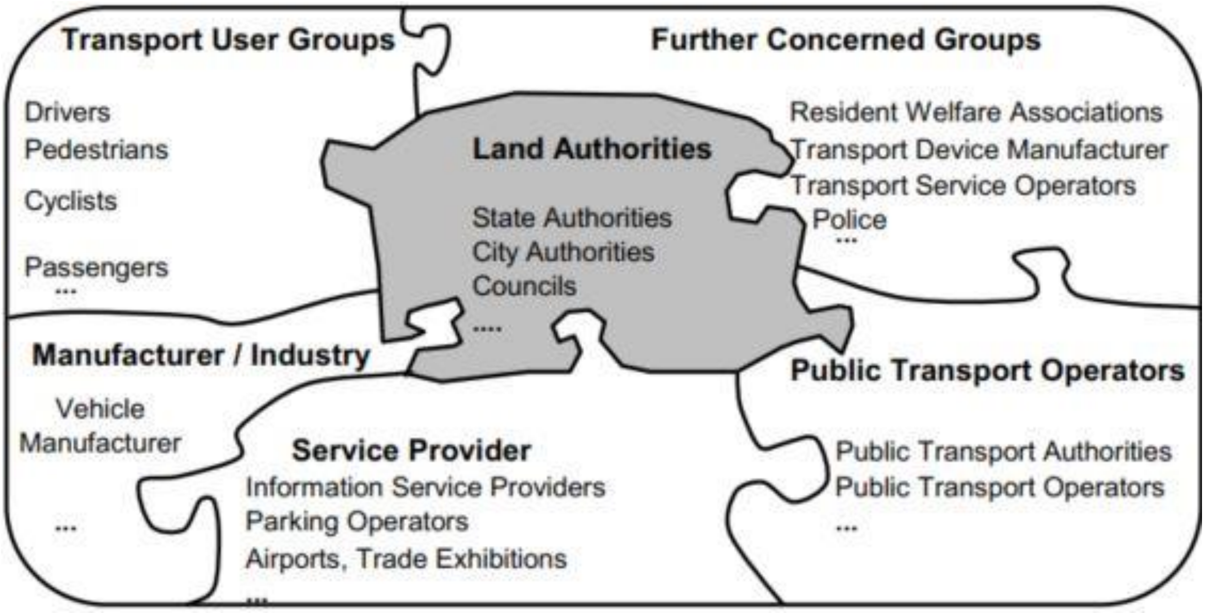

Figure 4.7 Stakeholders in transport demand management

Source: FGSV (2003)

Manufacturers / Industries

Manufacturers and industries produce transport vehicles and transport devices. Based on the policy of governments, manufacturers change the design of the body or engine of vehicles. For example, since several governments encourage more use of environmentally-friendly vehicles, numerous manufacturers try to provide electric and hybrid vehicles. They also pursue marketing strategies which attract more users to select their products. This means that producers are influenced by the policy of governments in implementing transport demand management measures.

Transport user groups

Transport user groups include pedestrians, cyclists, public transport passenger, and drivers of private vehicles. Travellers decide their mode of transport. Several factors impact their behaviour. Understanding the influential factors assists decision-makers in selecting suitable demand management measures to impact traveller behaviour. Transport user groups are also affected by negative impacts on the environment. User groups being aware of health impacts significantly supports the implementation of successful transport demand management measures.

Other concerned groups.

These groups include residents, police officers, transport device manufacturers, and transport service operators. The acceptance of residents plays a pivotal role in the success of transport management measures. Residents also benefit from transport demand management measures through reduction of gas emissions, noise pollution and other negative impacts. Raising the awareness of residents is a crucial transport demand management objective. Police officers may support implementing demand management measures, while other groups are influenced less directly by transport policy. A change in transport policy leads to a shift in transport device production and a shift in transport service demand.

4.4 Conclusions

This chapter considers health impacts in transport demand management. In this way, **a framework is proposed with the overall goal of health impact improvement**. Four objectives are targeted to provide orientation for selecting measures and developing strategies in the next steps.

Reviewing the research of transport demand management in the US, European countries and Asian countries **demonstrates the effectiveness of transport demand management** in improving air quality, reducing traffic congestion and noise pollution, and lessening other transport problems. **Moreover, transport demand management in Europe provides a valuable model for other regions and countries, particularly for developing cities.**

This chapter compiles the **list of feasible transport demand management measures for this study**. **Pricing measures have received the highest attention among assessing groups of measures**. Saleh & Sammer (2009) argue that pricing measures implemented in several cities around the world have proved effectiveness in reducing transport problems.

Since the **German method's effectiveness has been demonstrated in several case studies around the world, the strategy formation stage is applied from the German method.**

The role of stakeholders is crucial for the success of implementing transport demand management measures. Among the stakeholders, the group of users plays the most important role in achieving goals and objectives, particularly three objectives for passenger transport: "promoting the use of public transport", "promoting the use of non-motorised transport", and "reducing the use of individual motorised vehicles". **Understanding user behaviour supports the selection of strategies and measures**.

5 Case study: Transport demand modelling and management in Hanoi (Vietnam)

The first section of this chapter presents the status quo of the transport system and the health situation in Hanoi. The next section discusses survey methods and shows the data collection for generating the transport mode choice model. Then the method described in chapter 3 is applied to develop the transport mode choice model. This model is used to analyse transport mode choice behaviour in the case study. The final section provides a general view of negative health impacts in Hanoi, Vietnam. Then, transport demand management measures and strategies are developed to achieve the goals and objectives which are presented in chapter 4.

5.1 Transport and health situation in Hanoi

This section presents information on urbanisation in the case of Hanoi. Then the status quo of transport and the health situation are analysed.

5.1.1 Socioeconomic characteristics of Hanoi

Hanoi is in the central northern area of Vietnam. It is the 17th largest geographical city in the world at 3,358.6 Km^2. The urban area of Hanoi city has sprawled over time. The central area was formed a long time ago and was embraced by ring road No.1. The urban area has recently been expanded to ring road No.2, and outside of ring road No.3, and beyond, as shown in Figure 5.1.

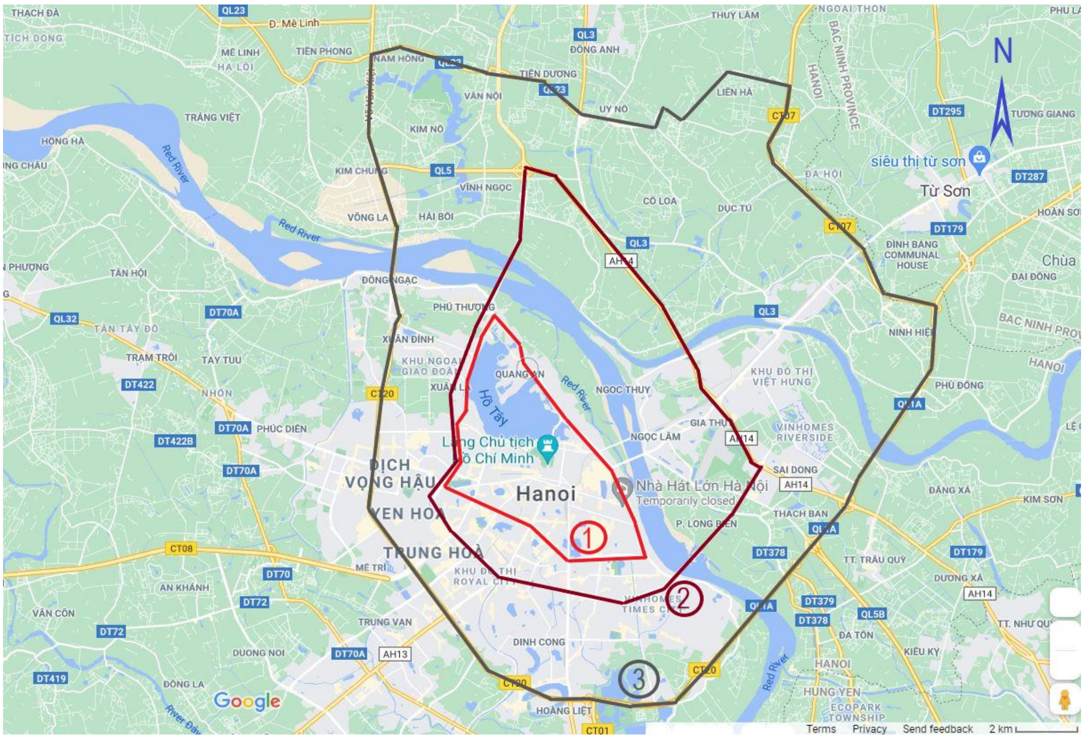

Figure 5.1 Urban area and three ring roads of Hanoi city

Source: Author's representation

Area and population density

The urban areas of Hanoi is 307.8 km^2 which accounts for 9.2% of the total area of the city. Hanoi has the second largest population in Vietnam (after Ho Chi Minh city), estimated at 8.054 million residents in 2019. The population of the urban areas is 3,460,300 people which accounts for 43% of the total population of Hanoi. The population density of the urban areas is very much higher than that of the rural areas. The highest population density is 42,302 people/km^2 in Dong Da district (Appendix 4.2). In some other districts in the rural areas the population density is only 1,000 people/km^2. This issue puts high pressure on the transport system in the urban areas. Hanoi is facing various transport problems such as congestion, air and noise pollution, traffic accidents, and severe health impacts.

Socioeconomic status

From 2013 to 2019, the economic growth rate of Hanoi was 9% per year. Personal income increased significantly. By 2019, Hanoi's gross domestic product was equal to 760,586 billion VND (approximately 29 billion Euro) (Hanoi statistical office 2019).

Hanoi has 75 universities, 27 colleges, and 388 vocational schools. The number of lecturers is 41,555. There are 947,440 students. The number of primary schools, secondary schools and high schools is 728, 617, and 212. The number of teachers is 170,091, and the number of pupils is 1,868,404 (Hanoi Statistical Office 2019). Hanoi is also a city with many industrial zones, tourist attractions, commercial centres, sports centres and health facilities.

5.1.2 Status quo of the transport system of Hanoi

Road transport infrastructure

Urban expansion influences the development of transport infrastructure. Hanoi urban area development is surrounded by ring roads: No.1, No.2, No.3. Recently, some new urban areas have also been developed outside ring road No.3.

Inside ring road No.1, the urban area has had a long history of development which has affected the characteristics of the road transport system. The road transport network was planned in grid lines in this area. The main features are road intersections spaced from 50 to 100 meters apart. Another characteristic is that the roads are narrow (only 6-8 meters). The road transport system in this area is suitable for small and low-speed vehicles such as bicycles, bicycle rickshaws, e-bikes, and motorbikes.

Inside ring road No.2, rapid growth of the urban area has led to the highest population density and put high pressure on the transport system. The area inside ring road No. 2 includes four central districts: Hoan Kiem, Ba Dinh, Hai Ba Trung, Dong Da, as shown in appendix 4.3.

The area between ring roads No.2 and No.3 includes residential and commercial zones in three districts Hoang Mai, Thanh Xuan, and Cau Giay, as shown in appendix 4.4. Transport demand in this area has increased significantly, while the development of the transport system has not kept up with the demand for transport. This has led to several transport problems such as congestion, traffic accidents, and air and noise pollution.

The urban area outside ring road No.3 sprawls over with six districts: Dan Phuong, Hoai Duc, Ha Dong, Thanh Tri, Nam Tu Liem and Bac Tu Liem, as shown in appendix 4.5. The population is predicted to reach 1.2-1.4 million residents by 2030. The orientation of these areas will include new urban areas with residential and commercial zones. Transport facilities are planned as well as other facilities. Road transport in two urban area expansions Red River and Southern Ca lo River include four districts Long Bien, Gia Lam, Dong Anh, and Me Linh, which are planned for future development, as shown in appendix 4.6.

Road transport in rural areas of Hanoi

The population density in rural areas is smaller than in urban areas. Therefore, transport demand in rural areas is lower than in urban areas. However, the quality of the road transport system is not good. There is a lack of facilities for public transport. As shown in appendix 4.7, the criteria of road transport of Hanoi's rural areas include twelve districts. Road density and the ratio of land for traffic are both low.

Parking system

Urbanisation has boosted population density in Hanoi city. Transport demand has increased dramatically. The number of vehicles has risen significantly. Consequently, the demand for road traffic and parking space has exceeded the available supply of the transport system. As a city in a developing country, Hanoi faces several parking problems such as illegal parking and individual parking behaviour (Truong 2018). In the urban area of Hanoi, the parking system is categorised in three groups: Long-distance coach stations, commercial transport stations and public parking spaces, as shown in appendix 4.8, 4.9.

Public parking spaces

There is an uneven distribution of parking spaces in Hanoi. They mostly are located inside transport ring road No.2. The number of parking spaces in three districts Hoan Kiem, Hai Ba Trung and Ba Dinh, is higher than in other districts. While Dong Da district, which has the highest population density has less area, and the number of parking spaces is smaller. Nam Tu Liem district has only 32 parking spaces, but the total area is the highest at 98,598 m^2. Three districts Cau Giay, Thanh Xuan, and Hoang Mai, located between transport ring roads No.2 and No.3 have medium numbers of parking spaces, but the total area is somewhat larger than in other districts. The other districts have smaller area and number of parking spaces, as shown in appendix 4.10. The total area of parking spaces in Hanoi is 340,390 square metres. Hanoi Transport Department assess that the supply of public parking spaces has not kept up with the increase in vehicle numbers, particularly in the centre of the city. This has led to illegal parking inside the city becoming common.

Infrastructure for bus operations

Hanoi has 96 terminals which provide services for buses. However, only ten terminals which integrate with long-distance coach services provide full services for buses. Other terminals are located in temporary spaces where there is a lack of services for buses and a lack of information for passengers.

Hanoi has 3,533 bus stops. However, they are mostly concentrated inside ring road No.3. In the estimation of Hanoi transport department, the average distance between bus stops is too far. Passengers find it very difficult to access bus lines.

The number of bus lines is increasing year by year. In 2011, Hanoi had 82 bus lines. By 2019, there were 127 bus lines in Hanoi (Figure 5.2).

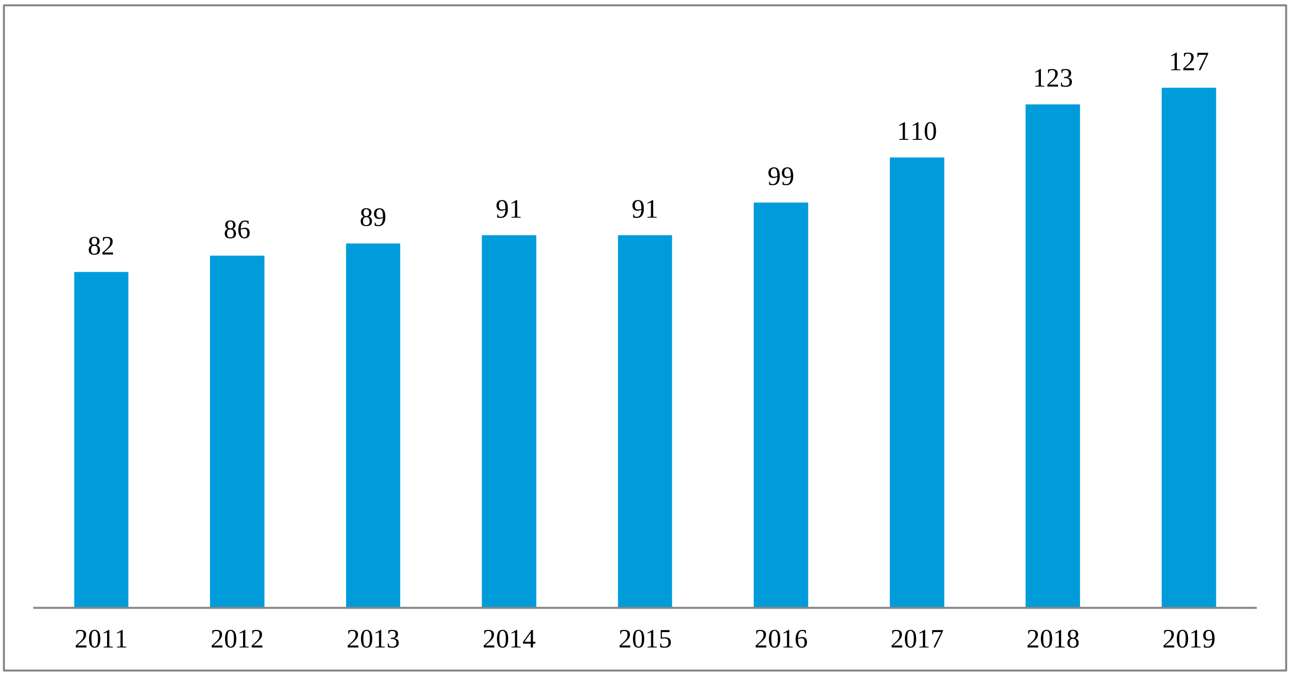

Figure 5.2 The number of bus lines in Hanoi, from 2011 to 2019

Source: Adapted from data of Hanoi Transport Department (2019)

Although the number of bus lines is huge, Hanoi only had one rapid transit bus line with a priority lane before 2019. Other bus lines must operate with normal traffic, including private cars, taxis, motorbikes and bicycles. This leads to low operating speeds. Because they are using the same lanes as other traffic, buses cannot keep accurately to schedule. Besides this, the traffic signal system is not programmed for bus priority. Consequently, the quality of the bus service is not good, and is unattractive to passengers.

Infrastructure for taxi service

Parking spaces for taxis are integrated into main stations, central commercial areas, and hotel forecourts. In the estimation of the Hanoi transport department, the number of spaces for taxi services is too small. In several main stations, demand for taxi service exceeds the number of parking lots. Sometimes, taxis cause traffic congestion near the main stations.

Infrastructure for cyclists, pedestrians, and disabled people

There is a lack of priority lanes for bicycles and adaptations for disabled people. Cyclists, pedestrians, and disabled people usually use pavements. However, motorbikes and private cars parked illegally on sidewalks cause difficulties for pedestrians. At the same time, road traffic is often obstructed by cyclists and pedestrians ignoring traffic signals.

Status quo of transport modes and public transport in Hanoi

Automobile and motorbike in Hanoi

According to the vehicle registration office, by 2019, Hanoi had 686,755 automobiles including 468,371 private cars. One unique characteristic of Hanoi is being a city which has 6,091,986 motorbikes. It is confirmed that Hanoi traffic is dominated by motorcycles (a motorcycle dependent city) Khuat (2006). Statistics of automobiles and motorbikes are shown in Table 5.1.

Table 5.1 Statistics of automobiles and motorbikes in Hanoi

Year	Automobiles					Total automobiles	Motor-bikes
	Private cars	Passenger Cars	Trucks	Specialised vehicles	Others		
2005	56,119	11,087	32,414	-	4,993	105,640	1,970,959
2006	64,329	11,456	37,363	-	5,891	119,039	2,152,270
2007	84,062	13,318	43,324	5,161	1,306	147,171	2,409,317
2008	111,650	14,623	51,943	5,629	1,795	185,640	2,837,810
2009	148,939	15,800	61,315	6,322	2,123	234,499	3,249,315
2010	180,396	16,270	71,319	3,191	2,365	273,541	3,577,041
2011	218,507	17,477	79,100	3,563	2,530	321,177	3,980,070
2012	226,810	18,334	82,786	3,681	2,788	334.399	4,444,127
2013	231,960	18,560	84,882	3,773	2,947	342,122	4,660,761
2014	255,658	19,702	93,572	3,947	3,538	376,417	4,852,380
2015	275,938	20,155	102,890	4,500	5,230	408,713	5,045,672
2016	327,820	23,141	123,841	5,304	5,849	485,955	5,360,746
2017	382,177	25,806	142,879	6,261	6,490	563,613	5,617,405
2018	425,363	27,483	156,453	6,893	7,476	623,668	5,831,707
2019	468,371	29,344	172,677	7,586	8,777	686,755	6,091,986

Source: Hanoi Transport Department (2019)

In 2005, The number of private cars was 56,119 vehicles. From 2005 to 2019, the growth rate of private cars was 16.77% per year. By 2019, the number of private cars was approximately eight times more than the number in 2005. From 2005 to 2019, the number of motorbikes increases three times, from 1,970,959 to 6,091,986 vehicles. This put high pressure on the road transport system.

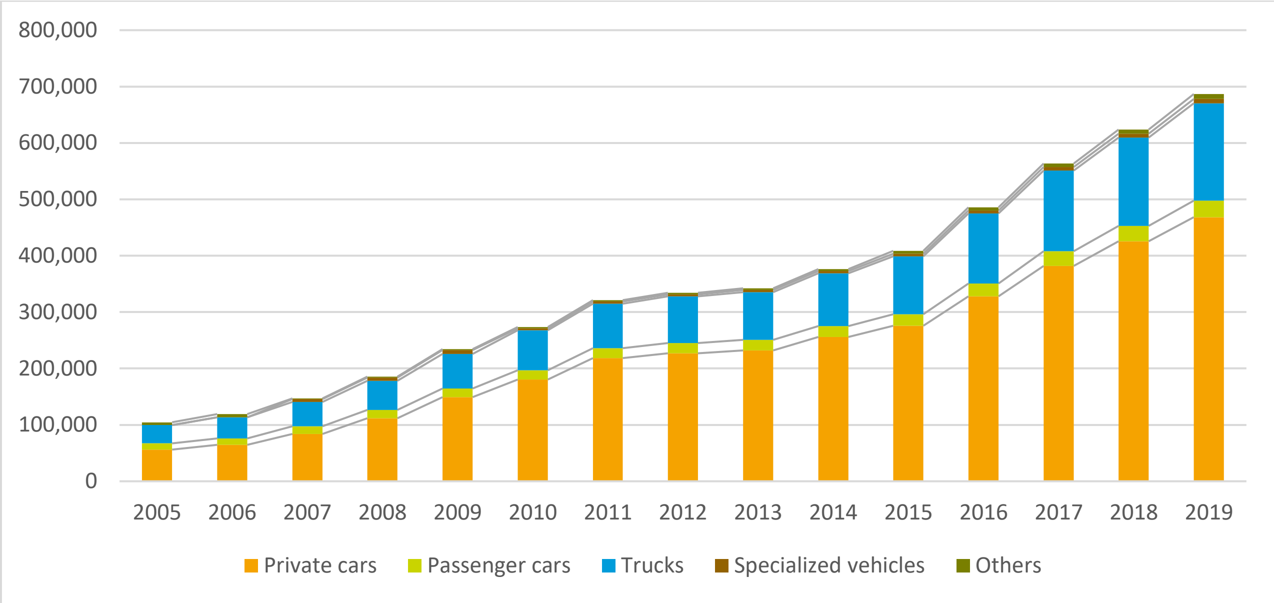

Figure 5.3 The number of automobiles in Hanoi, from 2005 to 2019

Source: Adapted from data of Hanoi Transport Department (2019)

From 2005 to 2019, the growth rate of automobiles was higher than that of motorbikes; however, the number of motorbikes is still much higher than the number of automobiles (Figure 5.3).

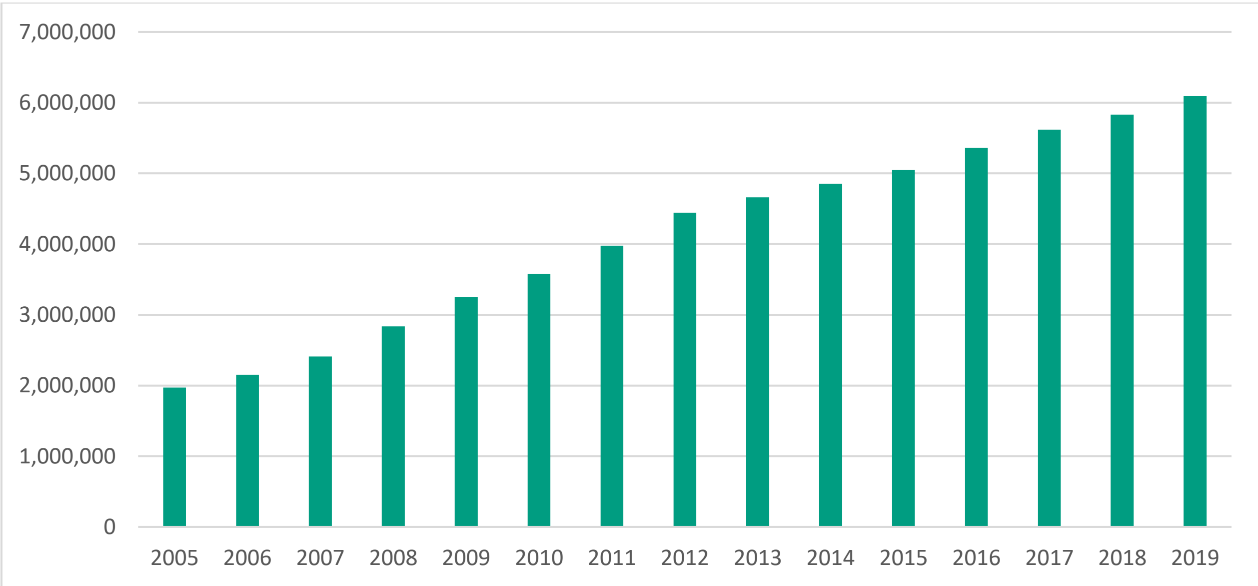

Figure 5.4 The number of motorbikes from 2005 to 2019 in Hanoi

Source: Adapted from data of Hanoi Transport Department (2019)

From 2005 to 2011, the motorbikes' growth rate was 12.46% per year. Although the growth rate decreased, the number of motorbikes rose dramatically. In 2006, the study of Hung (2006) confirmed that Hanoi is a motorcycle dependent city. At that time, Hanoi had only just over 2 million motorcycles. By 2019, Hanoi had over six million motorcycles (Figure 5.4). This situation creates a big challenge for transport planners and decision-makers.

Figure 5.5 shows the proportion of vehicle ownership in Hanoi. By 2019, the proportion of motorbike was the biggest ratio approximately 90%. The percentage of private cars is the second highest ratio equal to 6.91%. There is no statistical information regarding the number of bicycles and e-bikes ownership.

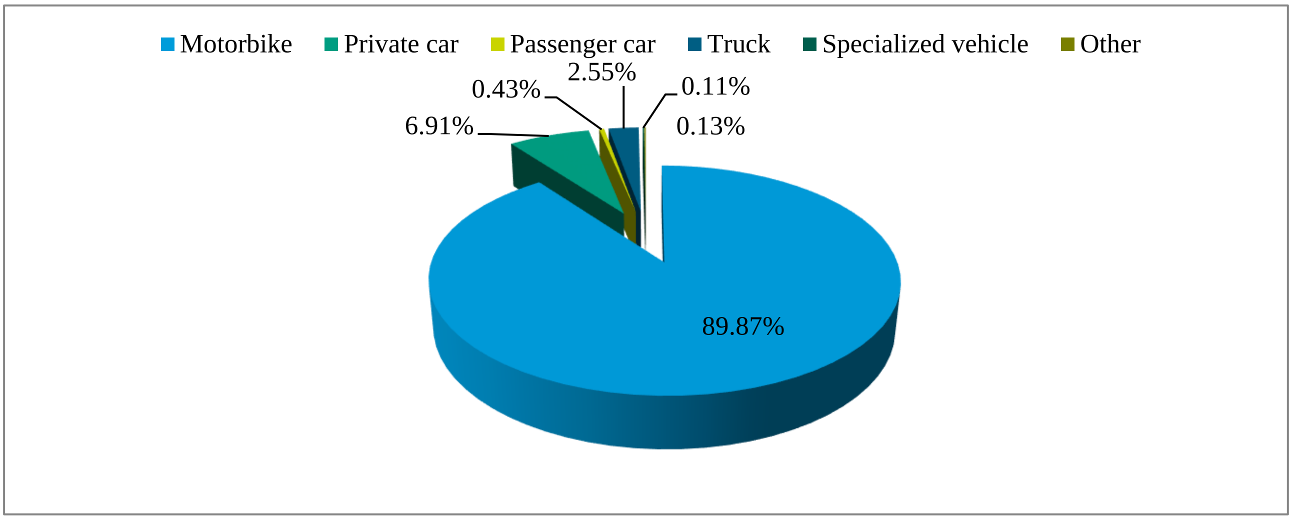

Figure 5.5 The proportion of registered vehicles in Hanoi

Source: Adapted from data of Hanoi Transport Department (2019)

Public transport modes

Until 2019, Hanoi's public transport modes included buses, taxis, contracted cars, tourist cars, hired buses, and other public transport modes.

The number of buses was 1,952. Almost all buses met emission standard Europe II and III. The number of buses which use compressed natural gas (CNG) was 102.

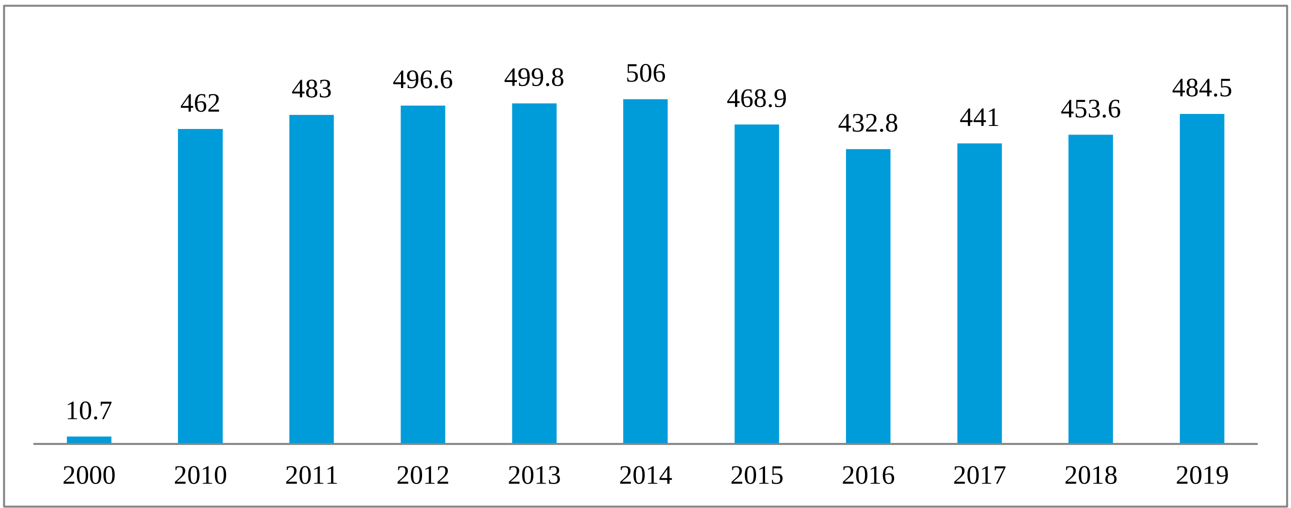

Figure 5.6 The number of bus passengers in Hanoi by year (million)

Source: Adapted from data of Hanoi Transport Department (2019)

In 2000, bus services carried only 10.7 million passengers. A decade later, the number of bus passenger trips had risen dramatically to 462 million. From 2010 to 2019, the number of passenger trips has fluctuated, with the highest number in 2014 at 506 million passenger trips (Figure 5.6).

In 2019, the number of trips by motorbike was the highest, accounting for 77.98% of traffic. Those of bus services and private cars were the second and third at 8.7 % and 4.99%. Those of other vehicle users: taxis, contracted cars, hired buses and other services met 1.97%, 3.35%, 1.13%, and 1.88% of the travel demand, respectively (Figure 5.7).

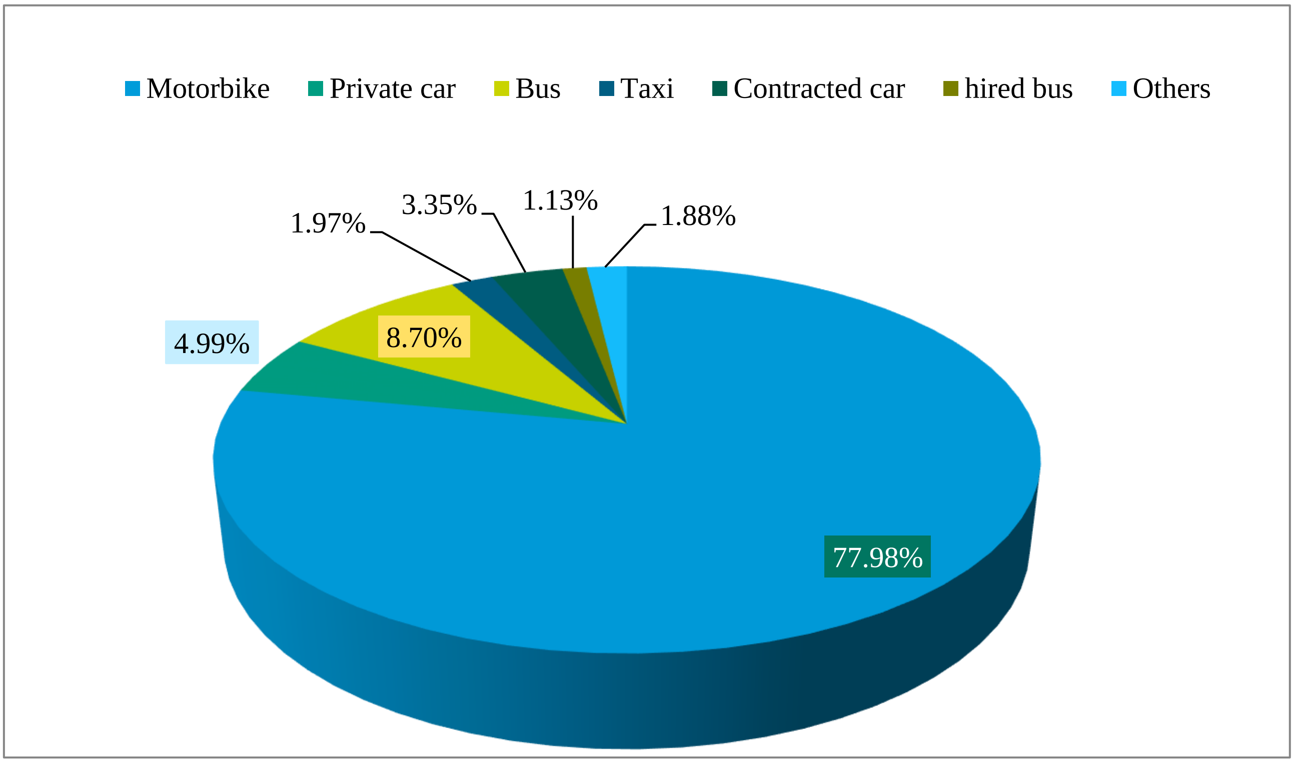

Figure 5.7 Traffic shares of passenger services in Hanoi

Source: Adapted from data of Hanoi Transport Department (2019)

Transport planning

According to Hanoi transport planning from 2020 to 2030, and orientation to 2050 of Hanoi People's Committee, Hanoi will continue to provide more road and urban railway facilities and improve the public transport system, as shown in appendix 4.1.

Parking space planning

By 2030, 4 long-distance coach stations are to change functions, as shown in appendix 4.11. Seven new long-distance coach stations are going to be built, as shown in appendix 4.12. By 2030, there will be 13 Park & Ride stations with 177,000 meters area of land. These Park & Ride stations are integrated with planned metro lines.

Public transport planning

Until 2025, Hanoi transport department plans for public transport according to certain criteria. Public transport will meet 30-35% of the demand for passenger transport. Urban railway and bus services will account for 4.5% and 18% of total demand, respectively. By 2030, public transport will meet 45-50% of the demand for passenger transport (equal to 11.29-12.55 million trips per day). The market share of public transport modes is presented in Table 5.2.

Table 5.2 The market share of public transport mode planning in Hanoi

	Urban railway (%)	**Bus (%)**	**Other public transport modes**					**Total (%)**
			Taxi (%)	**Contracted and tourist vehicles**		**Hired bus (%)**	**Others (%)**	
				Contracted car (Less than 9 seats) (%)	**Tourist vehicles (More than 9 seats) (%)**			
2025	3÷4,5	16÷18	2,5÷3	2,5÷3	3÷3,5	1,2	1,8	30÷35
2030	8÷10,3	25	2,5÷3	2,5÷3	4÷ 4,5	1,2	2÷3	45÷50

Source: Hanoi Transport Department (2019)

Hanoi plans to build 12 urban railways, including 09 metro lines and 03 monorail lines, as shown in appendix 4.13. Urban railway planning when implemented will provide high-quality public transport service for passengers. However, Hanoi has several difficulties with the financial budget, technical construction, and human resource skills for building and operating an urban railway system.

By 2030, Hanoi will provide eight bus rapid transit lines, as shown in appendix 4.14. The bus network is continuing under development with adjustments to integrate with the urban railway system.

By 2030, in line with Hanoi transport planning, the city will have 30,000 vehicles to provide taxi services. Taxis mostly operate inside ring road No.3, serving the airport, main stations and commercial centres.

5.1.3 Health impacts in Hanoi

Air pollutants

Air pollutants related to transport in Vietnam include total suspended particles (TSP), particulate matter PM_{10} and $PM_{2.5}$, SO_2, CO, CO_2, NO_2, and volatile organic compounds (VOC). Among air pollutants, the level of total suspended particles (TSP), particulate matter PM_{10}, and $PM_{2.5}$ are always higher than the Vietnam national standard (Vietnam Ministry of Natural Resource and Environment 2016). Notably, in comparison with other cities in the world, the level of $PM_{2.5}$ of Hanoi stays in the top ten in the ranking of the world's regional capital cities (WHO 2019). In Southeast Asia, Hanoi Vietnam was 6th in the list of most polluted regional cities.

WHO (2019) shows that 57.8% of annual hours were spent in dangerous $PM_{2.5}$ pollution levels in Hanoi. This imposes a severe impact on human health. By 2019, Hanoi was the most polluted city in Vietnam (WHO 2019). There were two months: July and August, when the level of $PM_{2.5}$ was at a moderate level. During the other months of the year 2019, the level of $PM_{2.5}$ was at an unhealthy level (WHO 2019).

According to Vietnam Ministry of Natural Resources and Environment, the air quality monitoring network showed that levels of SO_2, CO, CO_2, NO_2, and volatile organic compounds (VOC) routinely exceeded national standards in peak traffic hours. However, in other hours of the day, the level of those pollutants was below national standards.

In urban areas, there are several sources of gas emission including transport activities, the built environment, industrial activities and the daily activities of residents. However, emissions from transport vehicles contribute the biggest part of total emissions. Comparing transport modes, motorcycles generate the most emissions (Vietnam Ministry of Natural Resources and Environment 2016).

Noise pollution

Noise pollution has undergone a significant increase in urban areas of Vietnam in recent years. On the main streets or traffic corridors, noise level surpassed the national standard of noise from 6 AM to 9 PM every day (Vietnam Ministry of Natural Resources and Environment 2016). Figure 5.8 represents noise levels in urban areas of Vietnam.

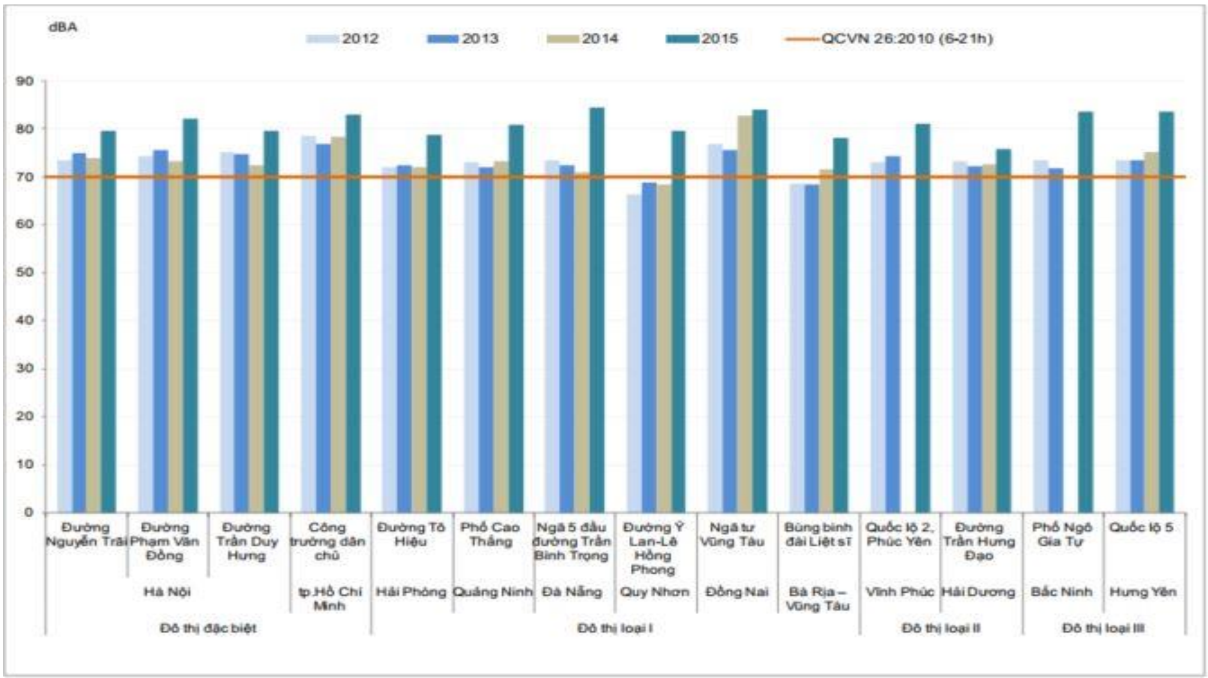

Figure 5.8 Noise levels in Urban areas of Vietnam

Source: Vietnam Ministry of Natural Resource and Environment (2016)

Phan et al. (2010) conducted intensive noise measurements in Hanoi and Ho Chi Minh city in 2005 and 2007. These authors indicate that the daily average noise level was $L_{Aeq,day} > 69$ dB in both of the two biggest cities in Vietnam. The main cause of noise pollution is the enormous number of motorbikes and frequent horn blowing (Phan et al. 2010).

Traffic accidents

Motorcycle use is primary cause of traffic accident, particularly in Vietnam. According to the WHO, 37% of road traffic deaths relate to motorcycles (WHO 2012). As mentioned in the previous chapter, the transport system of Hanoi is dominated by motorcycles (over 6 million motorcycles). Hence the majority of traffic collisions is caused by motorcycles. Nguyen (2009) found that the number of victims in motorcycle crashes with private cars accounted for 24% of casualties and the number of victims in motorcycle crashes with other motorcycles accounted for 16%. However, there are many minor collisions caused by motorcycles that are not recorded in the statistics.

Le et al. (2019) published a map of hotspots of road traffic accidents in Hanoi, as shown in Figure 5.9.

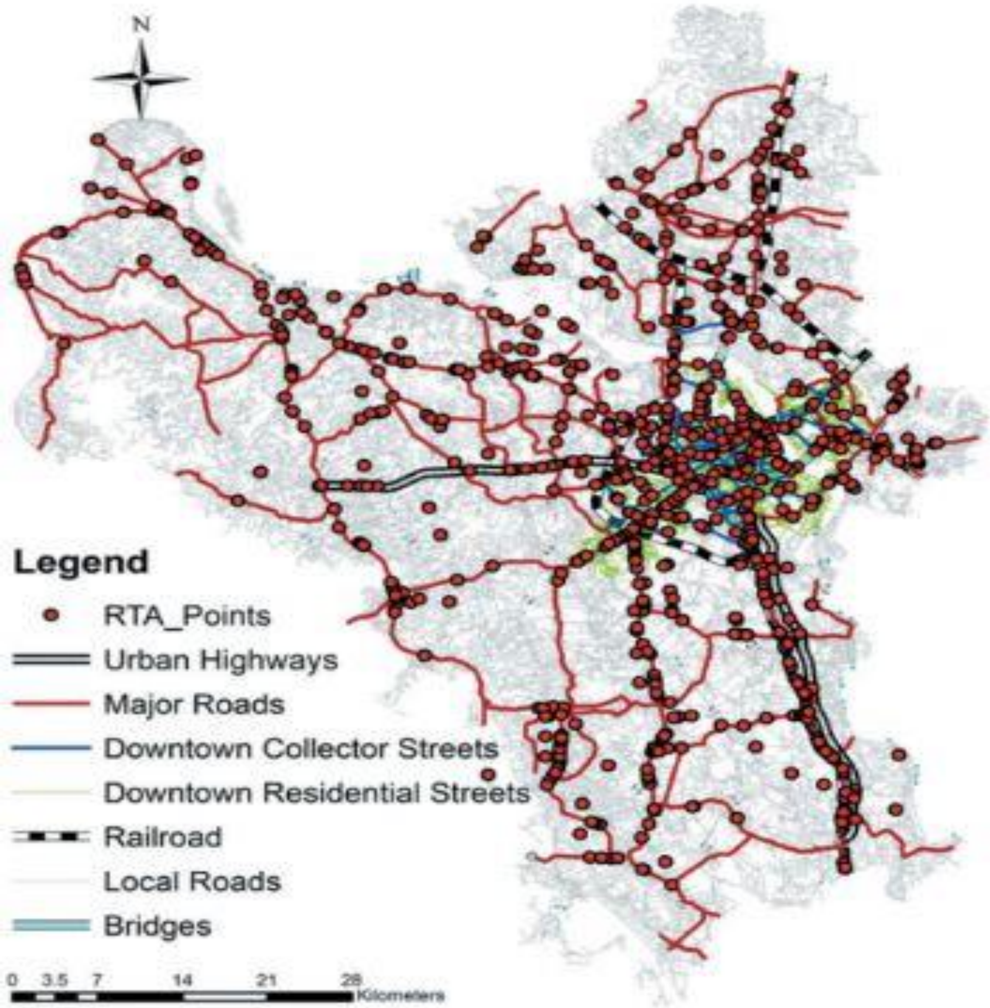

Figure 5.9 Hotspots of road traffic accidents (RTA) in Hanoi

Source: Le et al. (2019)

Le et al. (2019) used GIS-based temporal-spatial statistics to analyse the characteristics of road traffic accident in Hanoi from 2015 to 2017. The authors report some characteristics which are:

- Road traffic accidents tend to occur in specific time intervals of the year and day. The numbers of traffic accidents in December, January, and April are higher than in other months in the year. Every day, accidents are more frequent in two periods 14:00-15:00, and 19:00-23:00.
- There are many accidents at the intersections in the centre of Hanoi due to lack of signs and signal lights at intersections and a lack of pedestrian walkways.

Psychological stress

There are some particular causes of psychological stress in transport activities in Hanoi. Firstly, the domination of motorcycles in the transport system creates chaotic traffic flows, particularly at peak hours. Driving in chaotic traffic flows significantly increases the psychological stress of drivers. Secondly, according to Hanoi Transport Department, inside ring road No.3, there are 27 locations where traffic congestion usually occurred every day in 2019. Apart from those locations, traffic congestion sometimes builds up in the main streets and at transport hubs between, inside and outside of urban areas. These all cause psychological problems for drivers.

Pham (2017) reveals seven primary causes of traffic congestion in urban areas of Hanoi.

- Non-synchronous and unsustainable management, organisation, and implementation of transport planning.
- Poor awareness of road users.
- Increase of private vehicles.
- Non-synchronous transport infrastructure, narrow road cross-section.
- Unsatisfactory response to people’s demands on the public transport system.
- Weather conditions (Inundation, storms etc.).

5.1.4 Conclusions on the status quo of transport system and health situation in Hanoi

This section analyses urbanisation, transport system, transport planning and health impacts situation in the case Hanoi. It reveals some problems, as shown below.

Road transport

In the urban area the population is growing exponentially, leading to increased transport demand. However, the transport supply has not kept up with demand, leading to several transport problems and negative health impacts.

Parking system and facilities for public and active transport

Hanoi's parking system's notable feature is lack of parking space for both public and private transport. As a result, illegal parking has become very common. Hanoi's infrastructure generally lacks facilities for both public, private transport and active transport.

Public transport

Hanoi is a big city in both, population and area; however, until now, it has only provided bus and taxi services. Although the number of bus lines is increasing year by year, there is only one priority lane for a bus rapid transit line. On all other bus lines, bus vehicles operate in mixed traffic flow. Therefore, the standard of comfort, reliability, safety, and convenience does not satisfy the demand of travellers. In fact, the bus service is not attractive to passengers. This is a priority issue for policymakers and practitioners in improving public transport.

Status of transport modes and transport mode use

Statistical data confirms that motorcycles dominate the transport system in Hanoi with over 6 million vehicles. However, the growth rate of motorcycle numbers is slowing down, while the number of private cars is increasing at a faster rate.

The number of trips by bus transport was 484.5 million in 2019; however, this only accounted for 8.7% of total trips. Concurrently, the number of trips by motorcycle was 77.98% of the whole. This is a problematic situation for policymakers, planners, and practitioners.

Transport planning

This section gives the plan of the transport system in Hanoi. In general, Hanoi's government will provide more facilities for road transport, urban railway, and parking space. The authorities have also set high objectives for public transport. Nine new metro lines and eight new rapid transit bus lines are to be launched from 2020 to 2030. This is an ambitious plan for the limited investment budget of Hanoi.

Health impacts

Air pollution, noise pollution, traffic accidents, and psychological stress are the major causes of health impacts in the case study of Hanoi. Particularly, Hanoi's air pollution is in the list of the most polluted regional cities in Southeast Asia and in the world (WHO 2019). Daily average noise levels are always higher than the national standard. Road traffic accidents mostly arise at the intersections in the city centre. Travellers are faced with psychological stress when they travel in chaotic and congested traffic flows.

On the one hand, the domination of motorcycles is the main cause of several transport problems. On the other hand, motorcyclists are affected by these problems and their adverse health impacts. Besides, the growth in the number of private vehicles: private cars and motorcycles, will exacerbate the transport problems and health impacts.

Travellers are decision-makers about which transport mode they use. Hence, changing traveller behaviours' plays a pivotal role in solving transport problems and improving health impacts. In order to shift traveller behaviour, two steps are proposed:

- First, developing a mode choice model analyses factors which influence traveller behaviour.
- Second, selecting suitable transport demand management measures and forming a strategy which affects factors influencing mode choice behaviour. Changing mode choice behaviour with more users of public and active transport and less users of private transport lead to health impact improvements.

Step 1 is employed in section 5.2 of this chapter. Step 2 is implemented in section 5.3.

5.2 Transport demand modelling with consideration of health impacts

This section presents the data collection stage and selects a suitable survey method. Next, results from the model development process are shown. Finally, results are used to analyse the transport mode choice behaviour of travellers.

5.2.1 Design of survey instrument, data collection and database analysis

Design survey instrument methods

The aim of this section is to develop a transport mode choice model. Hence two suitable methods: revealed preference and stated preference, are relevant to designing the survey form. The revealed preference method designs questions which reveal the respondents' real choice and the observed individual's information. The stated preference method provides questions which assume several options; respondents make hypothetical decisions based on their knowledge of the situation. With the aim of better understanding traveller's mode choice behaviour, the design of this study's survey instrument is based on the revealed preference method.

Designing the survey instrument

The survey form is divided into three main parts. The first part is comprised of questions that describe the daily commute, mode choice, travel cost, and travel time of travellers. The second part contains questions on five latent variables: reliability, flexibility, comfort, convenience and health impact. The last part of the survey form is about the socioeconomic conditions of travellers.

Questions part I: Daily travel behaviour.

Question 1 asks information of the travellers' daily commute including origin address, destination address, distance from origin to parking space (bus stop), distance from parking space near the origin (bus stop) to parking space near the destination (bus stop), and distance from parking space near the destination (bus stop) to destination. This information is used to check the travel time of traveller in question 4.

Question 2 asks respondents which transport mode they choose for their daily commute. In Hanoi, the six options are motorbike, bus, car, e-bike, bicycle, and others.

Question 3 asks information about travel cost and is divided into two parts. The first part is for travellers who use private vehicles. In this part, there were some changes after doing a pilot survey. The initial version asked respondents about capital cost, maintenance cost, registration fees, toll fees, fuel cost, and parking fees. After doing the pilot survey, it was seen that almost all respondents answered that they do not remember exactly capital cost, maintenance cost and registration fees, and in Hanoi, they do not have toll fees. Therefore, the final version of the survey form removes questions about this information. The second part is used for travellers using public transport. When travellers choose the bus for their daily trip, surveyors ask respondents about the bus ticket they use. There are five bus tickets in Hanoi: monthly priority ticket on one-line, monthly priority ticket on multiple lines, monthly non-priority ticket on one-line, monthly non-priority ticket on multiple lines and the ticket for a single journey.

Question 4 asks for information about the travel time which respondents spend on their daily commute. This question is also divided into two parts for private vehicle users and public transport users. In the section for public transport, users provide information about the walking time, in-vehicle time, transfer and waiting time, and walking to destination. In the section for a private vehicle, users provide information about their in-vehicle time, access to parking time, and walking to destination.

Questions part II: Perception of different transport modes

Questions are designed to survey the attitude and knowledge of travellers. From reviewing previous studies about the hybrid choice model in chapter 3, four latent variables: reliability, flexibility, comfort, and convenience are chosen. With the aim of this study, health impact is added as a new variable.

For the question about reliability, three indicators can be selected: reliability of travel time, reliability of waiting time, and reliability of information. However, there are five transport modes: private car, bus, motorbike, e-bike, and bicycle in Hanoi's case study. After doing the pilot survey, it was found that private vehicle users did not give answers for all of the three indicators. People using private cars, motorbikes, bicycles, and e-bikes do not have waiting time or information in the context of their journey. Hence, this question was changed, which leaves only one indicator the “on time” travel.

The question about flexibility uses two indicators: ease of changing route and ease of changing time.

After considering the differences of the five transport modes in the pilot survey, comfort was also altered. This question now has one indicator: the comfort in/on the vehicle.

Two indicators "Ease of accessibility” and “Ease of transfer" are selected to measure convenience.

From the analysis in chapter 2, air pollution, noise pollution, safety, radiation, and psychological stress influence human health. Therefore, these five indicators are selected to assess the health impact awareness of travellers.

The indicators of latent variables are scored on a five-point scale from *not important* to *very important.*

Questions part III: Socio-economic characteristics

This part addresses the characteristics of the travellers: gender, age, income, education level, and children are surveyed.

Question 1 asks the gender of travellers.

Question 2 asks the age of travellers divided into five groups: under 23 years old, 23-33, 34-44, 45-55, and more than 55 years old.

Question 3 asks the income per month of respondents. There are five income groups: under 5 million (VND/month), 5-10 million, 10-15 million, 15-20 million, and over 20 million.

Question 4 asks about the education level of respondents and includes three groups: high school, bachelor degree and postgraduate degree.

Question 5 asks respondents about whether they have or do not have children.

Question 6 asks respondents which vehicles do they have.

A sample survey form is provided in appendix 5.

Results of data collection

The survey data were collected by performing face to face interviews in 600 households in Hanoi, Vietnam, in 2019. These households were randomly selected from the area between the West Station and the centre of the city. The success rate was 92.5 %, which means 555 households actually agreed and answered all of the questions on the survey forms.

Table 5.3 Descriptive statistics of the respondents

Socioeconomic Characteristics	Classification	Value in percentage (%)
Gender	Male	47
	Female	53
Age (year olds)	Up to 23	35
	23-33	42
	34-44	16
	45-55	5.4
	> 55	1.6
Income (Million VND)	Up to 5	37
	5-10	36
	10-15	16
	15-20	4.7
	> 20	6.3
Education level	High school	50
	Bachelor	44
	Postgraduate	6
Children	Having	31
	Not having	69

Source: Author's survey data

Descriptive statistics of the respondents are given in Table 5.3.

The sample gender ratio is 47% for men and 53% for women. The rate of vehicle ownership is 75% for motorbike, 11% for private car, 5% bicycle, 4% e-bike and 5% for owning no vehicle. These values are slightly different from the selection of transport modes for their daily commute which is 70% motorbike users, 6% private car users, 19% bus users, 2% bicycle users and 3% e-bike users of primary mode choice of travellers.

The most frequent age interval is observed as "23-33" years old with a ratio of 42%. The proportion of people in the three income groups under 5 million, 5-10 million and 10-15 million VND are 37%, 36% and 16%, while the percentages of the higher income groups are the less than others. The rate of respondents who are graduated from university and high school are 50% and 44%, and those of people who have postgraduate degree is only 6%. 31% of the respondents have children, while 69% of the respondent do not have children.

As mentioned above, since latent variables cannot be quantified in practice, the perceptions of trip makers are captured by qualitative questions. In this study, respondents rate the importance level on a five-point Likert scale ranging from not important to very important. Answering these questions generates perception indicators. Indicators are grouped on five latent variables: Reliability, flexibility, comfort, convenience, and health impacts. Table 5.18 presents the mean of perception for different transport modes in Likert scale (1 - not important, 2 - somewhat unimportant, 3 - median, 4 - somewhat important, 5 - very important).

In the five latent variables which are used in this study, flexibility, convenience and health impacts are multiple indicators because they use two questions or more (multiple-question). In order to check internal consistency of multiple indicators, Cronbach's alpha (α) is applied. Cronbach alpha coefficient for flexibility, convenience, and health impact are $\alpha_{flexibility} = 0.8$, $\alpha_{convenience} = 0.79$, $\alpha_{healthimpacts} = 0.86$. According to Nunnally (1978), a value of 0.7 implies acceptance. This means that all five latent variables are reliable to be used in the model.

As can be seen in Table 5.4, a remarkable characteristics is that the mean of indicator variables related to health impact of three groups of users bus, e-bike and bicycle are higher than those of the two other groups of users: private car and motorbike. This means that the three groups of users: bus, e-bike and bicycle assess health impacts as being more important than the two other groups of users. The mean of health impact indicator variables of e-bike user is the highest number while those of motorbike users is the lowest number. This means that e-bike users assess health impact as very important in choosing transport mode while motorbike users assess health impact as not so important in their selection.

Table 5.4 Observed mean perception for different transport modes

Latent variables	Indicators	Private car	Motorbike	Bus	E-Bike	Bicycle
Reliability	On time	4.32	4.19	4.4	4.31	4.17
Flexibility	Change route	3.73	3.76	4.16	3.84	3.75
	Change time	3.82	3.77	4.08	4.15	3.67
Comfort	Comfort in vehicle	4.05	3.83	3.88	4.00	3.5
Convenience	Accessibility	4.15	3.73	4.15	4.23	3.58
	Transfer	4.00	3.54	4.12	4.23	3.08
Health impacts	Air pollutant	4.00	3.97	4.08	4.77	4.33
	Noise pollution	4.09	3.91	4.17	4.54	4.25
	Safety	4.68	4.37	4.32	4.85	4.58
	Radiation	4.00	3.88	4.17	4.31	4.17
	Psychological stress	3.91	3.76	4.16	4.62	3.58

Source: Author's representation

5.2.2 Model development

This section describes the application of the theoretical model developed in chapter 3. A transport mode choice model is created to analyse travellers' behaviour in the case study of Hanoi city.

The aim of this research is to consider whether health impact awareness influences mode choice behaviour. From the literature review, a disaggregate modelling approach was found to be the most suitable for the objective and scope of this study. Based on random utility maximisation theory, a hybrid choice model which incorporates explanatory variables and latent variables has been developed. The model structure is shown in Figure 5.10.

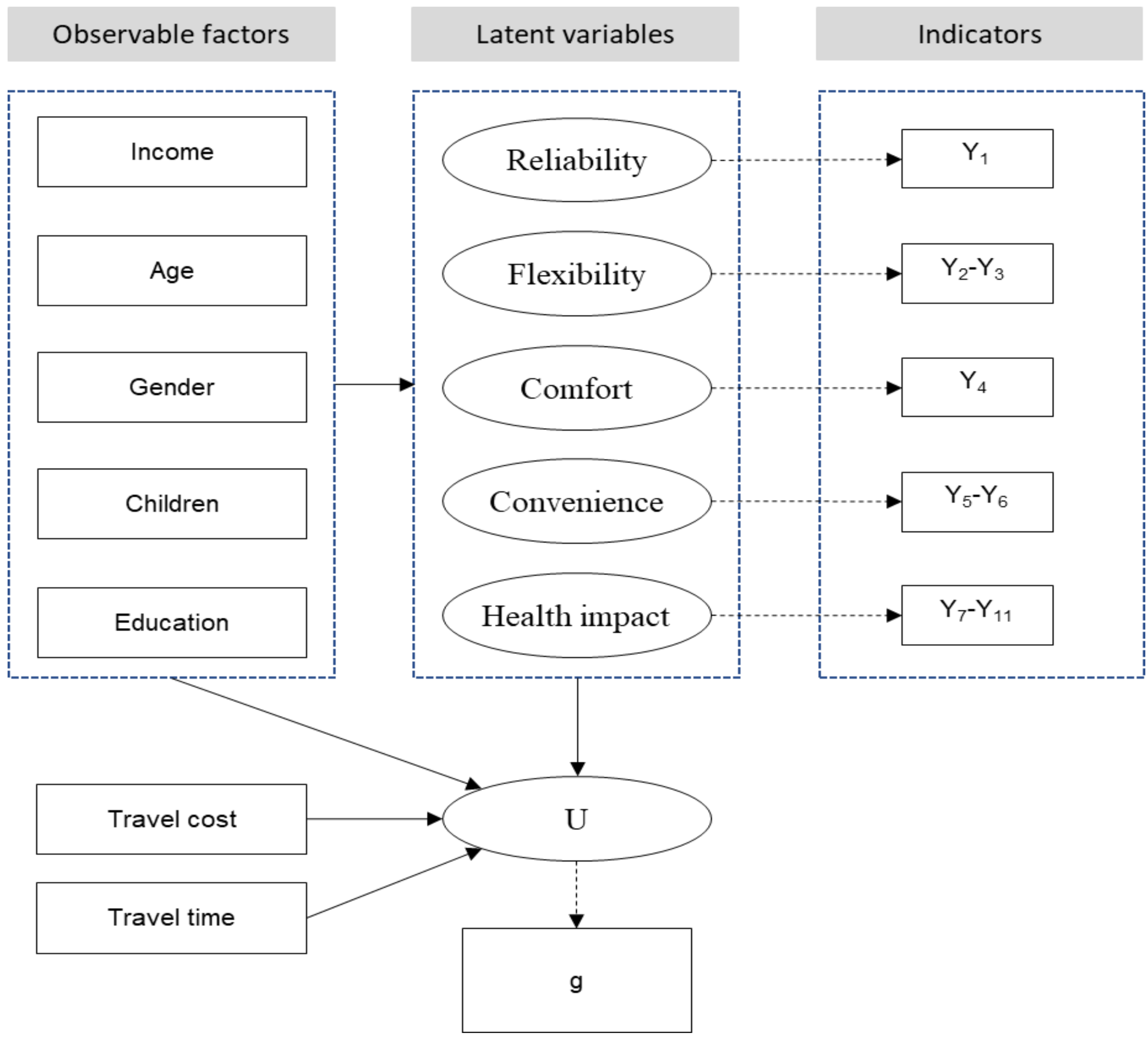

Figure 5.10 Structure of hybrid choice mode

Source: Author's representation

MIMIC model

In the first step, latent variables and indicators are used to estimate the MIMIC model. Explanatory variables are gender, age, income, education level and having children, which are included in the individual's latent variable functions. **Equation 4** is given by:

$$\eta_{li} = \alpha_{l1} * Gender + \alpha_{l2} * Age + \alpha_{l3} * Income + \alpha_{l4} * Education + \alpha_{l5} * Children \qquad (9)$$

where:

η_{li}: Latent variables (reliability, flexibility, comfort, convenience, health impact)

α_{l1}: Parameters of structure equation (9) which are estimated in Table 5.19

Estimating the structure and measurement equation in the MIMIC model is performed by using "*lavaan*" package in R programming (Rosseel 2019); the MIMIC model coefficients and significance values arse presented in Table 5.5 and Table 5.6.

Table 5.5 Parameters of structure equations *

Parameters	Gender	Age	Income	Education	Children
Reliability	0.111 (0.082)	-0.153 (0.001)	0.026 (0.506)	0.132 (0.046)	-0.089 (0.268)
Flexibility	0.121 (0.055)	-0.155 (0.001)	0.083 (0.034)	-0.032 (0.606)	-0.055 (0.471)
Comfort	0.057 (0.383)	-0.105 (0.021)	0.038 (0.342)	0.055 (0.421)	0.105 (0.203)
Convenience	0.173 (0.008)	-0.120 (0.008)	0.070 (0.063)	0.001 (0.986)	-0.032 (0.667)
Health impact	0.145 (0.018)	-0.049 (0.252)	-0.001 (0.985)	0.089 (0.164)	-0.060 (0.436)

**P-values are shown in parenthesis*

Source: Author’s representation

The parameters are accepted for evaluation with a P value less than 0.05. Accordingly, the structure equation in the MIMIC model is given by following **Equations 10-14**:

$$\eta_{Reliability} = -0.153 * Age + 0.132 * Education \quad (10)$$

$$\eta_{Flexibility} = 0.121 * Gender - 0.155 * Age + 0.083 * Income \quad (11)$$

$$\eta_{Comfort} = -0.105 * Age \quad (12)$$

$$\eta_{Convenience} = 0.173 * Gender - 0.12 * Age \quad (13)$$

$$\eta_{Health\ impact} = 0.145 * Gender \quad (14)$$

These equations are used to evaluate the values of latent variables, which are utilised in the hybrid choice model.

The results in Table 5.6 reveal that the parameters in measurement equations are positive and significant. From the results, all indicators were selected, which contribute to the construction of the latent preferences.

Table 5.6 Parameters in measurement equations

Parameters	Reliability	Flexibility	Comfort	Convenience	Health impact
(Y_1) On time	1.000				
(Y_2) Route change		1.000			
(Y_3) Change time		1.207			
(Y_4) Comfort in vehicle			1.000		
(Y_5) Accessibility				1.000	
(Y_6) Transfer				1.406	
(Y_7) Air pollution					1.000
(Y_8) Noise pollution					1.084
(Y_9) Safety					0.552
(Y_{10}) Radiation					1.118
(Y_{11}) Psychological stress					1.099

Note: The P-values of all parameters < 0.05, which reveal that all factors are statistically significant.

Source: Author's representation

Hybrid choice model

In order to estimate the hybrid choice model, the "*multinom"* function was used from the "*nnet"* package in R-Studio programming (*Statistical consulting group 2019)*.

The outcome level of the motorbike was selected as a baseline by specifying the "*relevel"* function since it is the most frequent mode. Then "*multinom"* function was utilised to estimate the model coefficients. Afterwards, p-values are calculated to check the significance of the relations.

The log odds ratios of the traditional discrete choice model can be calculated by using following equations 15-18:

$$Ln\left(\frac{P(Bicycle)}{P(Motorbike)}\right) = V_1 = \sum_k \theta_k . x_k \quad (15)$$

$$Ln\left(\frac{P(Bus)}{P(Motorbike)}\right) = V_2 = \sum_k \theta_k . x_k \quad (16)$$

$$Ln\left(\frac{P(EBike)}{P(Motorbike)}\right) = V_3 = \sum_k \theta_k . x_k \quad (17)$$

$$Ln\left(\frac{P(Private\ car)}{P(Motorbike)}\right) = V_4 = \sum_k \theta_k . x_k \quad (18)$$

Similarly, the log odds ratios of hybrid choice model can be estimated by using following equations 19-22:

$$Ln\left(\frac{P(Bicycle)}{P(Motorbike)}\right) = V_5 = \sum_k \theta_k . x_k + \sum_l \beta_l . \eta_l \quad (19)$$

$$Ln\left(\frac{P(Bus)}{P(Motorbike)}\right) = V_6 = \sum_k \theta_k . x_k + \sum_l \beta_l . \eta_l \qquad (20)$$

$$Ln\left(\frac{P(EBike)}{P(Motorbike)}\right) = V_7 = \sum_k \theta_k . x_k + \sum_l \beta_l . \eta_l \qquad (21)$$

$$Ln\left(\frac{P(Private\ car)}{P(Motorbike)}\right) = V_8 = \sum_k \theta_k . x_k + \sum_l \beta_l . \eta_l \qquad (22)$$

where:

θ_k: Parameters of explanatory variables x_k which are estimated in Table 5.7

β_l: Parameters of latent variables η_l which are estimated in Table 5.7

The discrete choice and hybrid choice modelling results are provided in Table 5.7.

Table 5.7 Parameters in traditional Discrete Choice Model and Hybrid Choice Model

Parameters	Multinomial logit without latent variables				Multinomial logit with latent variables			
	Bicycle	Bus	E-Bike	Private Car	Bicycle	Bus	E-Bike	Private Car
Gender	2.35	0.44	2.46	0.06	2.23	0.43	2.29	0.077
Age	0.22	0.23	-0.53	0.76	0.28	0.21	-0.43	0.72
Income	-1.33	-0.57	-0.62	0.63	-1.34	-0.57	-0.65	0.63
Education	0.37	-0.47	-0.24	0.23	0.37	-0.46	-0.25	0.24
Children	-10.34	0.53	-0.25	0.65	-10.26	0.53	-0.25	0.65
Cost	-0.000014	-0.000019	-0.0000025	0.0000025	-0.000014	-0.000019	-0.0000025	0.0000025
Time	-0.022	0.09	-0.0069	-0.005	-0.022	0.09	-0.007	-0.005
Reliability					0.007	-0.093	0.033	-0.079
Flexibility					0.116	-0.028	0.29	-0.05
Comfort					-0.029	-0.023	0.045	-0.076
Convenience					0.353	0.048	0.448	-0.074
Health impact					0.324	0.062	0.333	0.011
Intercept	-0.95	0.80	-2.12	-9.35	-0.951	0.8	-2.11	-9.35

Note: The P-values of all parameters < 0.05, which reveal that all factors are statistically significant.

Source: Author's representation

Multinomial logit with and without latent variables modelling results represent the probability of the parameter for a given transport mode compared to the likelihood of motorbike. These parameters can be used to interpret the change of four transport modes in comparison with the motorbike mode.

In the first row, coefficients are positive which means that the probability of the transit mode choice of bicycle, bus, e-bike and private car for women is higher than for men, compared to motorbike users when other parameters are kept constant. In the second row, the parameters of age for bike, bus and private car are positive, while that of e-bike is negative. This means that more travellers choose bicycle, bus and private car and fewer travellers choose e-bike than travellers choose motorbike when their age increases.

Coefficients of income of bicycle, bus and e-bike users are negative while that of private car users is positive. This means fewer commuters choose bicycle, bus and e-bike and more commuters choose private car than motorbike when income goes up. In other words, the number of passengers choosing bicycle, bus and e-bike go down, and those of traveller using private car rise when income rise. These trends reflect the real situation in urban areas of Vietnam. The number of private vehicles such as motorcycles and private cars has increased dramatically as the income of travellers has risen in recent years.

The coefficient of education reveals that travellers who have a higher level of education prefer bicycle and private car to motorbike. The number of higher education level passengers choosing bus and e-bike is lower than those of motorbike.

The coefficient of having children reveals that more travellers select bus and private car than motorbike, and fewer travellers select bicycle and e-bike than motorbike when they have children.

The parameters of travel cost and travel time show that the number of commuters using bicycle, bus and e-bike is less than those of motorbike, and the number of private cars is more than those of motorbike when travel cost rises. More travellers select bus than motorbike, and fewer travellers choose bicycle, e-bike and private car when travel time increases.

For the latent variables, the parameters of reliability and flexibility for bicycle and e-bike are positive, while the parameters of reliability and flexibility for bus and private car are negative. This means that travellers assess bicycle and e-bike as more reliable and flexible than motorbike, while they judge bus and private car as less reliable and less flexible than motorbike. The results are compatible with the real traffic situation in Hanoi city. People who use bicycle and e-bike are likely to be more punctual, while bus and car users are not on time in comparison with motorbike. Bicycle and e-bike are easier, and bus and private car are more difficult for changing route and changing trip plan than motorbike.

For comfort, the parameters of bicycle, bus and private car are negative, and those of e-bike is positive. It means that passengers assess bicycle, bus and private car to be less comfortable, while e-bike is more comfortable than motorbike. This is different from the expected assumptions. Normally, it is supposed that private cars and buses are preferred to motorbikes for comfort, but travellers prefer only e-bike to motorbike in terms of comfort.

Convenience parameters of bicycle, bus and e-bike are positive, but those of private car is negative. This means that users evaluate bicycle, bus and e-bike to be more convenient while private car is less convenient than motorbike. Commuters evaluate bicycle, bus and e-bike to be easier and private car to be more difficult in terms of accessibility and transfer compared to motorbike.

Health impact parameters of four transport modes bicycle, bus, e-bike and private car are positive. Four transport mode users evaluate health impact to be more important, and motorbike users assess health impact to be less crucial. In the Hanoi city traffic situation, indeed, motorbike users are faced directly with air pollution, noise pollution, radiation, unsafe condition and psychological stress. In other words, it can be concluded that there is compatibility between the real-world condition and interpreted results from the designed hybrid choice model.

Simulating the change of mode choice behaviour

Based on equation 15-18, the probability of each transport mode is identified. Probabilities of using transport modes from multinomial logit model without latent variables are:

$$P_{Motorbike} = \frac{1}{1+e^{V_1}+e^{V_2}+e^{V_3}+e^{V_4}} \quad (23)$$

$$P_{Bicycle} = \frac{e^{V_1}}{1+e^{V_1}+e^{V_2}+e^{V_3}+e^{V_4}} \quad (24)$$

$$P_{Bus} = \frac{e^{V_2}}{1+e^{V_1}+e^{V_2}+e^{V_3}+e^{V_4}} \quad (25)$$

$$P_{E-bike} = \frac{e^{V_3}}{1+e^{V_1}+e^{V_2}+e^{V_3}+e^{V_4}} \quad (26)$$

$$P_{Private\ car} = \frac{e^{V_4}}{1+e^{V_1}+e^{V_2}+e^{V_3}+e^{V_4}} \quad (27)$$

Based on equation 19-22, the probability for using each transport mode is identified. The probabilities of using transport modes from the multinomial logit model with latent variables are:

$$P_{Motorbike} = \frac{1}{1+e^{V_5}+e^{V_6}+e^{V_7}+e^{V_8}} \quad (28)$$

$$P_{Bicycle} = \frac{e^{V_5}}{1+e^{V_5}+e^{V_6}+e^{V_7}+e^{V_8}} \quad (29)$$

$$P_{Bus} = \frac{e^{V_6}}{1+e^{V_5}+e^{V_6}+e^{V_7}+e^{V_8}} \quad (30)$$

$$P_{E-bike} = \frac{e^{V_7}}{1+e^{V_5}+e^{V_6}+e^{V_7}+e^{V_8}} \quad (31)$$

$$P_{Private\ car} = \frac{e^{V_8}}{1+e^{V_5}+e^{V_6}+e^{V_7}+e^{V_8}} \quad (32)$$

In the case study of Hanoi, since the number of bicycle users and e-bike users is small, the change in number of bicycle and e-bike users are trivial. Therefore, this section measures the change of mode choice regarding motorbike, bus and private car, only. In order to measure the change of mode choice behaviour, three scenarios are created below.

Scenario 1: The assumption is that the travel cost of bus users reduce 10%, 15%, 20%, 25% and 30%. With these reductions, the changes of probability of bus and motorbike use are identified in Table 5.8. In reality, the transport demand management measures incentive for bus passengers or subsidy for operators in order to reduce bus fares.

Table 5.8 The changes of mode choice behaviour with scenario 1

Scenario 1	Variation	Multinomial logit model without latent variable		Multinomial logit model with latent variable	
		P_{bus}	$P_{motorbike}$	P_{bus}	$P_{motorbike}$
Reducing travel cost for bus users	10%	18.554%	-0.098%	18.552%	-0.099%
	15%	26.491%	-0.155%	26.489%	-0.158%
	20%	33.651%	-0.219%	33.648%	-0.222%
	25%	40.109%	-0.289%	40.106%	-0.292%
	30%	45.934%	-0.367%	45.931%	-0.371%

Source: Author's representation

As can be seen in Table 5.8, with the multinomial logit model without latent variables, if travel cost of bus users reduces 10%, 20%, 25%, and 30%, the probability of bus use increases 18.554%, 26.491%, 33.651%, 40.109%, and 45.934% respectively, while the probability of motorbike use decreases -0.098%, -0.155%, -0.219%, -0.289%, -0.367% respectively. In comparison with multinomial logit model with latent variables, the probability of bus use decreases slightly while probability of motorbike use increases slightly. The change of probability of motorbike use seems an insignificant number but with more than 6,000,000 motorbikes in Hanoi, the number of motorbike users will change substantially. For example, when reducing travel cost for bus users by 30%, the probability of motorbike use reduces by 0.371% (in the multinomial logit model with latent variables). This means that the number of motorbike users decreases by 22,269 users. This number is meaningful.

Scenario 2: The assumption of this scenario is that the travel time of private cars increases 10%, 20%, 25%, and 30%. With these increases, the changes of probability of private car and bus use are identified in Table 5.9. In reality, transport demand management measures: access control, restrictions and speed management can increase the travel time of private cars.

As can be seen in Table 5.9, if travel time of private car increases 10%, 15%, 20%, 25%, and 30%, the probability of private car use decreases while the probability of bus use increases. Therefore, with the aim of reducing the use of private vehicles, transport demand management measure need to increase the travel time private vehicles.

Table 5.9 The changes of mode choice behaviour with scenario 2

Scenario 2	Variation	Multinomial logit model without latent variable		Multinomial logit model with latent variable	
		$P_{private\ car}$	P_{bus}	$P_{private\ car}$	P_{Bus}
Increasing travel time for private car users	10%	-0.0130%	1.612%	-0.0133%	1.611%
	15%	-0.0197%	2.408%	-0.0200%	2.407%
	20%	-0.0263%	3.198%	-0.0269%	3.197%
	25%	-0.0331%	3.981%	-0.0338%	3.980%
	30%	-0.0399%	4.758%	-0.0406%	4.757%

Source: Author's representation

Scenario 3: The assumption of this scenario is that the two measures reducing travel cost for bus users and increasing travel time for private car users are introduced currently. The changes of mode choice behaviour are presented in Table 5.10.

Table 5.10 The changes of mode choice behaviour with scenario 3

Scenario 3	Variation	Multinomial logit model without latent variable		Multinomial logit model with latent variable	
		P_{bus}	$P_{private\ car}$	P_{bus}	$P_{private\ car}$
Reducing travel cost for bus users and increasing travel time for private car users	10%	19.865%	-0.112%	19.864%	-0.114%
	15%	28.258%	-0.179%	28.256%	-0.187%
	20%	35.767%	-0.252%	35.765%	-0.256%
	25%	42.486%	-0.334%	42.483%	-0.339%
	30%	49.497%	-0.425%	48.494%	-0.432%

Source: Author's representation

As can be seen in Table 5.10, that when combining the two measures: reducing travel cost for bus users and increasing travel time for private car users, the probability of bus use increases, the probability of private car use decreases. However, the increase of probability of bus use in scenario 3 is higher than that for bus use in scenario 1, and the decrease of probability for private car use also is higher than that for private car use in scenario 2. This demonstrates that the combination of both measures for private vehicles and public vehicles leads to a significant change in mode choice behaviour.

5.2.3 Conclusions on the transport mode choice model with consideration of health impacts

This section discussed the data collection process. To ensure the reliability of data, the process of data collection was divided into stages. Through these stages, the survey form was adjusted before doing the definitive survey in the case study. In this study, each surveyor selected random households and did face-to-face interviews with a paper-pencil instrument.

The result demonstrates two important issues.

- **First, the model development process in chapter 3 can be used to develop a feasible mode choice model.**
- **Second, hybrid choice model is a suitable model to analyse mode choice behaviour with consideration health impact awareness.**

The results confirmed that seven observable factors and five latent variables significantly influence travellers' mode choice behaviour in the case study of Hanoi. **Particularly, the results illustrate that health impact awareness is an important influencing factor of mode choice behaviour.**

The transport mode choice model results reveal that income increase leads to more use of private vehicles, including motorcycles and private cars. This reflects the reality of the circumstances of the transport system in Hanoi city. If policymakers do not take any action, the number of private vehicles will continually increase. Transport problems and negative health impacts will multiply.

In order to measure the change of mode choice behaviour, three scenarios were created. **The results illustrate that transport demand management can change mode choice behaviour.**

The results also illustrate other factors: travel cost, travel time, reliability, flexibility, comfort, convenience, and health impact awareness all affect traveller behaviour. The results of parameters of five latent variables illustrate that the group of motorbike users assesses health impacts to be less important than other groups of transport users. **Raising awareness about health impacts for motorbike users could change their mode choice behaviour.** Based on these results, transport demand management measures will be selected. Demand management strategies will be employed to change traveller behaviour.

5.3 Transport demand management with consideration of health impacts

Section 5.3.1 shows the transport problems and health impacts in Hanoi, Vietnam. Then, section 5.3.2 selects suitable transport demand management measures to solve problems for negative health impacts. Finally, section 5.3.3 develops transport demand management strategies for the case of Hanoi, Vietnam.

5.3.1 Transport problems and health impacts in Hanoi

As mentioned in section 5.1.1, there are several transport problems in Hanoi’s urban areas. These problems are the main causes of the negative health impacts which are analysed in section 5.1.2.

Public transport problems

- There is a lack of public transport services. Albeit Hanoi is a megacity, it has only bus and taxi services. An urban railway is under construction and planned to provide services in the future.
- There is a lack of bus priority lanes. Bus vehicles operate in the same lanes as private vehicles. The chaotic traffic flow due to the motorcycle stream influences the reliability of bus services.
- The reliability, safety, convenience, quality, and bus information system do not satisfy the demands of travellers. This is the reason why the number of bus users is small (accounting for only 8.7% of total passengers).

Non-motorised transport issues

- There is a shortage of non-motorised transport facilities. This deficiency leads to low numbers of non-motorised transport users.
- The deficiency of sidewalks, bicycle lanes and pedestrian crossing facilities adversely affect the safety of non-motorised transport.
- Walking space is reduced by illegal parking.

Private vehicles problems

- The domination of motorcycles causes several negative health impacts such as gas emissions, noise pollution, traffic accidents and psychological stress.
- The growth rate of the number of private cars is leading to severe traffic problems.

Health impacts problems

- Air pollutants stay at dangerous levels for human health. There is a shortage of equipment monitoring air quality.
- Noise on the road is higher than the recommended standard of the WHO due to both engine and horn sound.
- There are traffic accidents mainly relate to motorcycles.
- Psychological stress of travellers is mainly caused by chaotic traffic flow.
- There is a lack of resident awareness about health impacts.

As analysed in section 5.1, the domination of motorcycles in Hanoi is the main cause of negative health impacts. Additionally, the growth rate of the number of private cars is rapid and suggests that the use of private cars will increase dramatically in the future. This will lead to more harmful health impacts. Therefore, the switch from private vehicle use to public and active transport use will play a pivotal role in improving human health. This identifies three main modal objectives of passenger transport: To promote the use of public transport, to promote the use of active transports, and to reduce the use of private vehicles.

Results from the transport mode choice model in section 5.2 illustrate that the awareness of health impacts of travellers influences their mode choice behaviour significantly. Hence, raising the awareness of travellers about health impacts supports the modal objectives as shown in Figure 4.3.

To sum up, in order to reduce adverse health impacts on travellers in this case study of Hanoi, Vietnam, there is a need to implement concurrently management of transport planning, traffic supply and transport demand, as well as raise travellers' awareness. However, as mentioned in section 5.1, Hanoi government has established a transport plan in which transport supply will be improved with more facilities for an urban railway system, bus system, park-and-ride locations, and active transport. Therefore, the next section of this chapter focuses on transport demand management and raising the awareness of travellers.

5.3.2 Transport demand management measures

Chapter 4 reviewed traffic management measures and transport demand management measures. This section compiles transport demand management measure for the case study of Hanoi.

Based on the list of measures which is presented in chapter 4, this section distils suitable measures for the situation of the case study of Hanoi.

Measures which influence transport demand are categorised in the following groups:

- Individual motorised transport measures are measures which impact on the demand for private vehicle use. The objective of these measures is to reduce motorcycle use, and to decrease the growth rate of private car use.
- Public transport measures are measures which affect the demand for public transport. The objective of these measures is to promote public transport use.
- Active transport measures are measures which influence the demand for active transport. The objective of these measures is to promote active transport use. However, these measures should be considered for application when the air quality is improved and negative health impacts are reduced.
- Raising awareness measures are supportive measures. Since awareness is a significant factor which influences transport mode choice behaviour, raising the awareness of travellers supports the change of mode choice behaviour. Besides, awareness of health impacts encourages travellers to select transport modes which improve human health and reduce negative health impacts.

Measures for individual motorised transport

Table 5.11 shows the list of measures to reduce the negative impact of individual motorised transport. As mention in chapter 4, groups of fiscal measures: “Mobility pricing/ road pricing”, “Oil tax and vehicle tax”, “Pollution pricing”, “Congestion pricing”, and “Private vehicle ownership taxation” are demonstrated to be effective in reducing private vehicle use. Less private vehicle use leads to a decrease in harmful impacts such as air pollution, noise pollution, traffic accidents and other negative health impacts. Groups of fiscal measures can be implemented for the whole city, or for a particular route. To implement these measures, the government of state or city should plan pricing schemes (where and when and the amount to toll), toll infrastructure and appropriate technologies.

Two measures: “Parking management” and “Access control and restriction” influence private vehicle use in a selected area, or on a specific route. Authorities must decide which locations or areas and infrastructures will employ these measures.

Speed management is an important measure to reduce traffic accidents in urban areas. This measure can be employed in a particular area or on a selected route. The government of state or city publishes its policy of speed management and can use Intelligent Transport System (ITS) to monitor velocity.

Five measures: “Dynamic individual guidance and information systems”, “Intermodal individual guidance and information systems”, “Automatic lateral guidance of vehicles”, “Car2car/Car2 infrastructure communication” and “Driver assistance systems” are modern measures which support private vehicles in adapting to traffic situations. Depending on the financial budget, authorities may offer ITS support for these measures.

“Vehicle emission improvements” is a measure which reduces gas emissions and noise pollution. This measure should be applied in urban areas where there are numerous older, more polluting vehicles, particularly in developing countries. Authorities should encourage vehicle suppliers by supporting the training of staff to encourage drivers to buy less polluting vehicles.

"Carpooling and other Ride Sharing Programs" are measures to increase efficient vehicle use. More efficient vehicle use decreases the number of trips by private vehicles. This measure needs sponsorship from the government, employers and the compliance of travellers.

Table 5.11 Individual motorised transport measures

	Measures		Reduction of motorcycle use	The decrease of private car use
Individual motorised transport	1.1	Mobility pricing/ Road Pricing	x	x
	1.2	Oil Tax and Vehicle Tax	x	x
	1.3	Pollution pricing	x	x
	1.4	Congestion pricing	x	x
	1.5	Private vehicle ownership taxation	x	x
	1.6	Parking management	x	x
	1.7	Access control and restriction	x	x
	1.8	Speed management	x	x
	1.9	Dynamic individual guidance of vehicles		x
	1.10	Intermodal individual guidance and information systems		x
	1.11	Automatic lateral guidance of vehicles		x
	1.12	Car2car/Car2Infrastructure communication		x
	1.13	Driver assistance systems		x
	1.14	Vehicle emission improvements	x	x
	1.15	Carpooling & other ride sharing programs	x	x

Source: Author's representation

The effectiveness of individual motorised measures depends upon some supportive systems. As mentioned in each measure above, three systems can be used for individual motorised transport measures are "Toll infrastructure", "Intelligent transport system" and "Vehicle maintenance service".

Some requirements for implementing individual motorised transport measures are facilities, staff training and financial budget. Facilities are needed to set up toll infrastructure, intelligent transport system and other supportive systems. Operating these systems need to be trained staff. Carrying out these systems requires financial budget.

Measures for public transport

Table 5.12 shows the list of measures for public transport. Since bus vehicles are operating with other vehicles in chaotic traffic flows, bus services have difficulty in keeping time on published schedules. This means that bus services are not reliable, and convenient for passengers. Bus services do not satisfy the demands of passengers for reliability, convenience and quality of service. Also, signal control systems in Hanoi do not give priority to buses. Therefore, two measures: "Right of way "prioritisation", "Public transport priority" are proposed to improve bus services. In order to implement these measures, policymakers and planners of Hanoi should reconfigure vehicle lanes on the road network. These changes to traffic operations and the road network are the responsibility of the government of state or city.

The measure “Schedule improvement” is introduced with the aim of ensuring that bus services meet the demands of passengers. Bus service operators have the responsibility of implementing this measure. Providers of bus service should invest in computer-aided operator systems for this task.

The measures “Fare arrangement” and “Public transport subsidy-individual/groups” aim at different passenger groups. The price of tickets should be appropriate for each group of passengers. Providers should consider subsidies for appropriate passenger groups. This task requires a uniform policy of the government of state or city. Authorities should consider the financial budget needed to implement this task.

The measure “Public transport subsidy-operators” aims at subsidising bus service providers. This measure not only focuses on the imbalance of revenue and cost of operations, but also serves to encourage the provision of higher quality public transport. This task is the responsibility of the government of state or city in both publishing the policy and providing the necessary financial budget.

Table 5.12 Measures for public transport

		Measures	Lack of Priority lane	Lack of Priority Signal control	Less Reliability	Inconvenience	Lack of Information	Low Quality	Lack of subsidy for passengers
Public transport	2.1	Public transport priority		x					
	2.2	Right of way prioritisation	x		x	x		x	
	2.3	Schedule improvement			x	x			
	2.4	Fare arrangement							x
	2.5	Public transport subsidy-operators			x	x	x	x	
	2.6	Public transport subsidy-individual/groups							x
	2.7	Improving access to public transport			x	x			
	2.8	Personalised para-transit services				x			
	2.9	Passenger information systems				x	x		
	2.10	Quality management			x	x	x	x	

Source: Author’s representation

The measures “Improving access to public transport” and “Personalised para-transit services” aim to improve access of passengers by requiring the redesign of pavements and crosswalks of road networks. Authorities of state or city should publish their policy to implement these measures.

The measures “Passenger information systems” and “Quality management” aim at providing better services for passengers. Public transport providers should provide more information of services in vehicles, at the stations and at the stops. Passengers need to be able easily to check “Information services” with the devices they have. Operators should set up a system of quality management which makes services more attractive to passengers.

To ensure the effectiveness of public transport measures, there is a need for some supportive systems such as “Computer-aided operator systems”, “Ticket system”, “Signal control” and “Information system”. Computer-aided operator systems can support measures: “Schedule improvement”, “Passenger information systems” and “Quality management”. Ticket systems support measures: “Fare arrangement” and “Public transport subsidy-individual/groups”. Signal control systems support measures: “Public transport priority”, “Right of way prioritisation”, “Improving access to public transport” and “Personalised para-transit services”. Information system support measures: “Improving access to public transport”, “Personalised para-transit services”, “Passenger information systems”, and “Quality management”.

Some requirements for implementing public transport measures are facilities, training staff, financial budget. Facilities are needed for signal control system, ticket system and information system. Using computer-aided operator systems and information systems requires staff to be trained. Financial budget is needed to be invested in facilities, training staff.

Measures for active transport

Table 5.13 show the list of measures for active transport. A remarkable feature of the case study of Hanoi is the lack of facilities which support active transport. Therefore, measures for promoting active transport focus on providing more facilities.

The measures “Establishment of pedestrian routes” and “Walkability improvement” aim at improving the pedestrian network. For the case study of Hanoi, firstly, illegal parking on pavements should be prevented. Secondly, more crosswalks on the streets should be provided. Finally, signal controls for pedestrians should be improved. All these measures require the sponsorship of the government of state or city.

The measures “Establishment of bicycle routes” and “facilities for sidewalks and bicycles” expand the bicycle network and provide more facilities for sidewalks and bicycles lanes. Facilities include signal control systems and parking spaces.

Table 5.13 Measures for active transport

		Measures	Lack of facilities	Lack of sidewalks	Lack of bicycle lanes	Illegal parking on sidewalks
Active transport	3.1	Establishment of pedestrian routes		x		x
	3.2	Establishment of bicycle routes			x	
	3.3	Facilities for sidewalks and bicycles	x			
	3.4	Establishment of priority zones for active transport	x	x	x	x
	3.5	Cycle subsidy				
	3.6	Bike/Transit integration	x			
	3.7	Public bike systems	x			
	3.8	Walkability improvements				x

Source: Author's representation

The measure "Establishment of priority zones for active transport" establishes areas for active transport. This measure reflects the benefits of active transport for urban residents. It nurtures a habitual use of active transport.

The measure "Cycle subsidy" encourages more active transport use. It may be a subsidy for the price of vehicles or for investment in facilities. While the measure "Bike/Transit integration" supports travellers in integrating bicycle use with public transport. This measure requires improvement of vehicles and supportive facilities. Providing more public bike systems and parking facilities at public transport stations can encourage this trend.

The supportive system which is needed for active transport measures is signal control system. Requirements for implementing active transport are facilities and financial budget. Facilities are used to set up signal control system. It is also needed to reconfigure road network with bicycle lanes and pedestrian routes. Supportive systems and requirements of active transport measures are needed financial budget.

Measures for raising health impact awareness

Table 5.14 shows the list of measures for raising health impact awareness. In the case study of Hanoi, residents lack information about pollution and other negative health impacts. Also, they also do not know which level of pollutants influences their health. Hence, raising public awareness about health impacts plays a pivotal role in changing traveller behaviour. In order to implement this measure, the government of state or city should invest in more monitoring systems which signal the threshold of pollution levels. Authorities also must publish information of pollution levels, the current number of traffic accidents and report of traffic congestion. Additionally, media systems should be used broadcast more information about the current status of negative health impacts.

To ensure the acceptance of residents of changes of travel demand, mode choice and traffic peaks, three measures "Agreements to influence travel demand", "Agreements to influence modal choice", and “Agreements to eliminate traffic peaks” are implemented. These measures require several preliminary surveys such as online surveys and face to face interviews. These measures can be initiated by authorities or transport operators.

Two measures “Traffic education and driver training” and “Training from experts” are aimed at drivers. These measures improve the skill and knowledge of drivers to reduce traffic accidents and traffic congestion. These measures must be implemented by transport operators for their drivers.

Two measures “Media campaigns to promote walking/cycling/public transport” and “Increase awareness of public transport services” aim at raising awareness of travellers about the benefits of public and active transport. These measures influence the mode choice behaviour of travellers. To employ these measures, authorities should present more information about the benefits of public transport and active transport at public spaces and on media systems.

To ensure the effectiveness of raising awareness measures, there is a need for some supportive systems “Monitor system”, “Information systems”, “Media systems” and “Survey systems”. In order to provide health impact information for community, it is needed has monitor system. This system collects information of air quality, noise pollution and other negative health impacts. Information system support measures “Traffic education and driver training” and “Increase awareness of public transport services”. Media system is used to raise public awareness about health impacts and employ media campaigns about active and public transport. This attracts attention of travellers about benefit health of active and public transport. Survey system should be set up to investigate agreements of travellers about raising awareness measures. To ensure the effect of raising awareness measures, it is needed facilities, training staff and financial budget.

Table 5.14 Measures for raising health impact awareness

		Measures	Lack of information of health impacts	Lack of acceptances	Problems in driving process
Raising awareness	4.1	Raising public awareness about health impacts	x		
	4.2	Agreements to influence travel demand		x	
	4.3	Agreements to influence modal choice		x	
	4.4	Agreements to eliminate traffic peaks		x	
	4.5	Traffic education and driver training			x
	4.6	Training from experts			x
	4.7	Media campaigns to promote walking/cycling/public transport	x		
	4.8	Increase awareness of public transport services	x		

Source: Author’s representation

5.3.3 Transport demand management strategies

Applying the German method (FGSV 2003) which was presented in chapter 4, this section develops transport demand management strategies for the case study of Hanoi, Vietnam. The formation of strategies is based on the list of problems, measures, supportive systems, and requirements which is presented in the previous section.

There are four strategy masks, for individual motorised transport, public transport, active transport and raising health impact awareness.

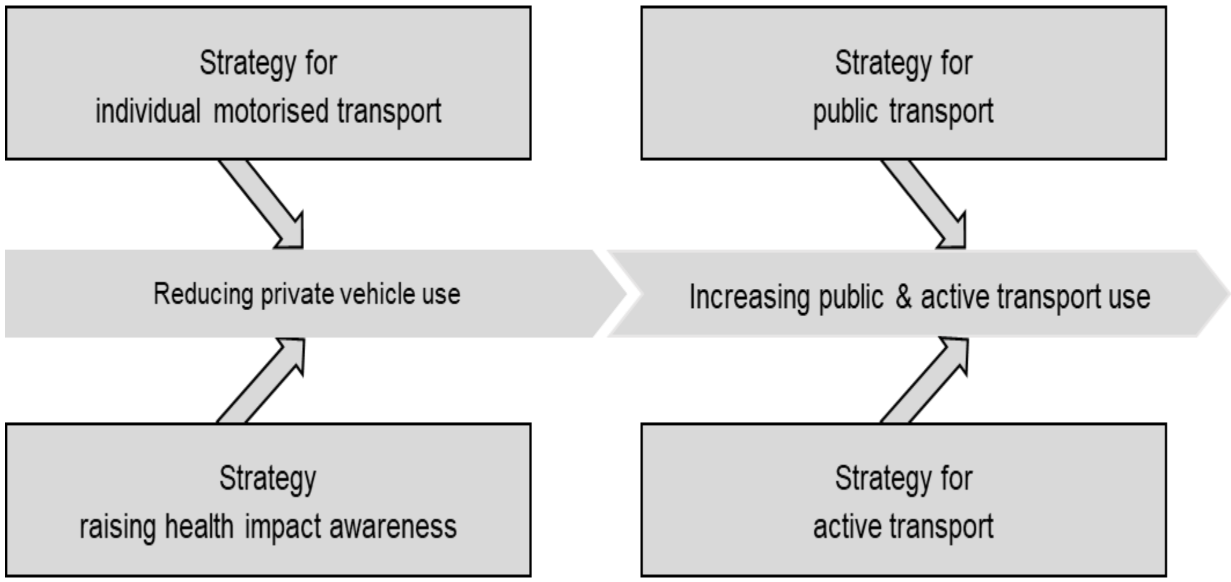

Figure 5.11 Combination of strategies

Source: Author's representation

The combination of strategies ensures the efficiency of implementation (figure 5.11). Since the strategy for individual motorised transport influences the behaviour of private vehicle users, the acceptance of private vehicle users assures the success of implementation. Hence, employing a strategy for individual motorised transport comes together with a strategy for raising awareness. A strategy for public transport is associated with a strategy for active transport to attract more users of public and active transport.

Strategy for individual motorised transport

Individual motorised transport strategy aims at reducing private vehicle use, particularly reducing motorcycle use in the case study of Hanoi (figure 5.12).

Strategy Mask

Situation
Individual motorised transport

- The domination of motorcycle use
- The increase of private car use

Strategy	
1.1	Mobility pricing/ Road pricing
1.2	Oil tax and vehicle tax
1.3	Pollution pricing
1.4	Congestion pricing
1.5	Private vehicle ownership taxation
1.6	Parking management
1.7	Access control and restriction
1.8	Speed management
1.9	Dynamic individual guidance of vehicles
1.10	Intermodal individual guidance and information systems
1.11	Automatic lateral guidance of vehicles
1.12	Car2car/Car2 infrastructure communication
1.13	Driver assistance systems
1.14	Vehicle improvements
1.15	Carpooling & other ride sharing programs

Systems to be used

- Toll infrastructure
- Intelligent transport system
- Vehicle maintenance services

Need for action

- Facilities
- Staff training
- Financial budget

Figure 5.12 Strategy mask for individual motorised transport

Source: Author’s representation

The responsibility for implementing an individual motorised transport strategy belongs to Hanoi People’s Committee. Authorities establish policies for fiscal and non-fiscal measures. They invest in infrastructure and decide where and when to implement measures.

Strategy for public transport

Public transport strategy aims at attracting more users to public transport (figure 5.13). This strategy should improve connections with other transport modes for example adding bicycle parking at public transport stations or transit stops.

Strategy Mask

Situation

Public transport

- Lack of priority lanes
- Lack of priority signal controls
- Less reliability
- Inconvenience
- Lack of information
- Low quality
- Lack of subsidy for passengers

	Strategy
2.1	Public transport priority
2.2	Right of way prioritisation
2.3	Schedule improvement
2.4	Fare arrangement
2.5	Public transport subsidy-operators
2.6	Public transport subsidy-individual/groups
2.7	Improving access to public transport
2.8	Personalised para-transit services
2.9	Passenger information system
2.10	Quality management

Systems to be used

- Computer-aided operator systems
- Ticket systems
- Signal control systems
- Information systems

Need for action

- Facilities
- Staff training
- Financial budget

Figure 5.13 Strategy mask for public transport

Source: Author's representation

The responsibility for implementing the public transport strategy belongs to Hanoi People's Committee and public transport operators. The authorities plan public transport networks. They decide on reconfiguration of street lanes and improve accessibility of public transport. Authorities make decisions about how much budget to spend on subsidies. Operators have responsibility for ensuring the reliability, safety, comfort and convenience of public transport. They also manage the quality of public transport.

Strategy for active transport

Active transport strategy aims at encouraging more active transport users (figure 5.14). However, implementation of this strategy should take into account the environmental conditions and other relevant health impact factors.

Strategy Mask

Situation
Active transport

- Lack of facilities
- Lack of sidewalks
- Lack of bicycle lanes
- Illegal parking on pavements

	Strategy
3.1	Establishment of pedestrian routes
3.2	Establishment of bicycle routes
3.3	Facilities for sidewalks and bicycles
3.4	Establishment of priority zones for active transport
3.5	Cycle subsidy
3.6	Bike/Transit integration
3.7	Public bike systems
3.8	Walkability improvements

Systems to be used

- Signal control systems

Need for action

- Facilities
- Staff training
- Financial budget

Figure 5.14 Strategy mask for active transport

Source: Author's representation

The responsibility for the implementation of active transport strategy belongs to Hanoi People's Committee. The authorities plan bikeway and sidewalk networks. They also decide on the reconfiguration of streets when adding bicycle lanes. The authorities provide the budget for subsiding active transport.

Strategy for raising health impact awareness

Raising awareness strategy plays a pivotal role in supporting the three strategies above. In other words, three strategies: Individual motorised transport, Public transport, and Active transport cannot be realised without a raising awareness strategy (figure 5.15).

Strategy Mask

Situation
Raising awareness

- Lack of information of health impacts
- Lack of acceptance
- Problems in driving process

	Strategy
4.1	Raising public awareness about health impacts
4.2	Agreements to influence travel demand
4.3	Agreements to influence modal choice
4.4	Agreements to eliminate traffic peaks
4.5	Traffic education and driver training
4.6	Training from experts
4.7	Media campaigns to promote walking/cycling/public transport
4.8	Increase awareness of public transport services

Systems to be used

- Monitor systems
- Information systems
- Media systems
- Survey systems

Need for action

- Facilities
- Staff training
- Financial budget

Figure 5.15 Strategy mask for raising awareness

Source: Author's representation

The responsibility for implementing the raising awareness strategy belongs to Hanoi People's Committee. Raising awareness strategy should be implemented in steps:

- Classifying travellers in groups of which the group of motorbike users must receive priority attention.
- Surveying focus groups.
- Analysing level of awareness of health impacts and the negative impacts of using private vehicles, and the positive impacts of using public and active transport.
- Developing campaigns to implement raising awareness strategy.
- Evaluating the efficiency of the strategy.

5.3.4 Conclusions on transport demand management with consideration of health impacts

This section considers health impacts in transport demand management for the city Hanoi.

Since the transport planning of Hanoi reveals that transport supply is already planned for the future, this section focuses on transport demand management. Based on the compiled list of transport demand management measures, measures corresponding to defined transport problems are selected. Selected measures are classified into four groups: “Individual motorised transport”, “Public transport”, “Active transport”, and “Raising awareness”. The systems and requirements for the implementation of each group are identified. **The German method which connects directly appropriated measures to solve problems is feasible for case studies including Hanoi.**

To solve defined problems in the case study of Hanoi, the German method is applied to develop strategies. There are four strategies corresponding with the four groups of measures defined in the previous section. The strategy masks are presented as a result of strategy development. **The strategies with measures, supportive systems and requirements ensure the success of transport demand management.**

German method is successful in developing traffic management strategies in countries. With the case of Hanoi, **it is the first time applied for transport demand management.**

To ensure the effectiveness of strategy implementation, the roles of stakeholders are identified. The assessment of the efficiency of strategies is considered as a step in the implementation process. **To ensure the effectiveness of transport demand management strategies, they should be implemented consistently. Strategy for raising health impact awareness plays a very important role in supporting other strategies.**

The effectiveness of strategy implementation in this study is expected that **the negative health impacts of transport in Hanoi will be reduced and the positive health impacts will be increased.**

6 Conclusions

This chapter begins with a summation of the study. In more detail, the formulated questions in chapter 1 are answered, thus providing the formal contribution of this study. Then, major conclusions, observations and findings are shown. The final section discusses the future scope of the study.

6.1 Summary

In 2006, for the first time, Hanoi was confirmed a motorcycle dependent city (Khuat 2006). At that time, Hanoi had over 2 million motorcycles and confronted several traffic problems. The study of Khuat (2006) proposed several traffic management strategies applicable in the case of Hanoi. Consequently, institutions and policymakers in Hanoi published several plans and traffic management schemes to solve traffic problems. Several transport infrastructures were financed, and the government also provided more public transport services. However, over ten years later, the number of motorcycles is three times higher than in 2006, and the number of motorbike users accounts for an approximately 80% market share of passenger services. An exponential increase in private vehicle use degrades air quality, increases noise pollution, traffic accidents as well as other negative health impacts.

The difficult traffic situation in Hanoi is exacerbated by the authorities paying more attention to traffic supply, while transport demand management is neglected. This explains why the number of private vehicles in use has increased faster than supporting infrastructure. If this trend is not reversed, the negative health impacts will worsen. With the overall goal of human health improvement, this study applies the methodology of the German Transport Planning process. Following the German method, the different parts of the study are sketched.

Chapter 1 briefly shows the motivations, goals and objectives, methodology, structure and research questions of this study. This chapter presents the orientation research for the whole study.

As a phase of problem analysis in the German methodology, the first section of **chapter 2** provides a basic description of other parts of the study by answering question *Q1: How can health impacts in transport be defined?* The definitions of health impacts and the basic definitions related to health impacts are presented. The next section describes the interdependencies of urbanisation, motorised transport, and health impacts. In general view, the conceptual framework of health impacts confirmed that transport mode choice plays a pivotal role in supporting human health or causing adverse health impacts. **Answering question Q1, terminologies related to health impacts of transport activities are clarified.**

Chapter 2 also reviews existing regulations and acceptance thresholds of health impacts around the world. It reveals that German regulations have been updated with the latest version becoming the leading standard for other European countries. This explains why Europe has become a successful region in realising health impact improvement in the world. **This study suggests applying German regulations to the case study of Hanoi, Vietnam.**

In order to find the opening for this research and to answer question *Q2: What is the status quo of research on health impacts in transport*? Chapter 2 also reviews research on health impacts throughout the world. This section observes that most of the research on the health impacts of transport is carried out in developed countries. **The deficiency of research on health impacts in developing countries reflects the actual situation of serious negative health impacts** in several countries. Another gap is revealed where there are several research studies on health impacts but **no research on how health impact awareness influences transport mode choice behaviour**. In studies of health impacts, **transport modes: bicycle, public transport, private car, travel on foot has received more attention than motorcycle.** The literature review also discovered that transport demand management influences transport mode choice behaviour. **Some research demonstrated that shifting transport strategy is the most effective way to reduce negative health impacts.**

Filling one of the gaps found in chapter 2, question *Q3: How can a transport demand model be developed?* is answered in **chapter 3**. The first section lays the groundwork for this chapter by presenting definitions relating to a transport demand model. In order to determine the most suitable approach for developing a transport mode choice model which considers the health impact awareness factor, the next section reviews the way to develop transport mode choice.

There are two approaches to develop transport mode choice behaviour. The first is the aggregated approach. This approach is based on the four-step model which represents the behaviour of a group of travellers by collecting aggregate data. The data provides an average over the group of travellers. The results analyse the transport mode which a group of travellers chooses. The model can be used to predict the future demand of the group of travellers. The aggregate model is applied for general transport planning.

The second approach is the disaggregated approach. This model is used to present individual behaviour by obtaining data from each traveller. Analysing the data provides understanding of how impact factors influence travellers' behaviour. Two groups of factors which are observable and latent variables have been analysed in several previous studies. Observable factors include socioeconomic characteristic of travellers such as age, income, education level, gender etc. Latent variables are the psychology and attitudes of travellers. **Since health impact awareness is also a latent variable, the disaggregated approach is the most suitable for developing a transport mode choice model.**

There are several theories which support the developing model process. They are classified in three groups: psychological theories, traditional economic theory and geographical theory.

Psychological theories examine psychological factors which impact the behaviour of travellers. There are some remarkable psychological theories such as the theory of planned behaviour and the transtheoretical model of health behaviour. These theories initially were applied to analyse the behaviour of smokers, then transferred to examining the behaviour of travellers. However, the behaviour of travellers is not only affected by psychological factors but also by socioeconomic factors.

Geographical theory develops activities-based models. This type of model can be used to analyse travellers' behaviour; however, it is not suitable for collecting data at different locations or over periods of a day or a week.

Traditional economic theory analyses socioeconomic impact factors. However, this model does not take account of psychological factors.

In order to overcome the limitation of the theories above, **a state-of-the-art transport demand model has been developed, known as the hybrid choice model.** This model incorporates both observable factors and latent variables to avoid the weaknesses of the models above.

Section 3.3 discusses scope of transport demand model. From that, scope of transport demand model in this study is identified. Then, **the next section of this chapter proposes a model development process** in which steps are discussed in more detail. Based on the model development process, **in section 3.4, a transport mode choice model with consideration of health impacts is developed.** This is the foundation of the model for application in chapter 5.

Chapter 4 answers question *Q4: What transport demand management measures are feasible?* **The first section clarifies two concepts: traffic management and transport demand management**. Traffic management influences both transport supply and transport demand, while transport demand management impact only transport demand. In other words, transport demand management is a component of traffic management. Because of the restriction of space in urban areas and the limits imposed by financial budgets, transport supply cannot meet an exponential growth of transport demand. Hence, several developed countries focus on transport demand management to change travellers' behaviour. This provides valuable experience for developing countries, particularly relevant to the case study of Hanoi, Vietnam, where there is tight restriction on financial budget for transport. This section also discusses the characteristics of transport demand management which can be applied in different locations or over wide ranging areas, and at different times as well as for different travel markets. With the clarified concept of transport demand management, this section presents the set of goals and objectives which lead to the next sections. **The basis framework for transport demand management with consideration of health impacts is proposed with the aim health impact improvement**.

Section 4.2 shows the state of development of transport demand management with health impacts. This section of chapter 4 reviews the study of transport demand management in the world. Experience from the US and European countries demonstrates that **reducing private vehicle use is an effective strategy for solving transport problems and improving health impacts**. The experience of European countries has been applied successfully in Singapore which is in turn valuable experience for developing countries. Some studies reveal that pricing measures are the most effective mean of changing travellers' behaviour. The barriers to employing pricing measures are now effectively removed by the development of appropriate information technology. One benefit of fiscal measures is the generation of revenue which can be used to enhance the transport investment budgets of cities.

The next section of chapter 4 reviews research on traffic management and transport demand management. **A list of measures is presented,** being the material for the next step: developing strategies by the German method. This section answer question *Q5: How transport demand* *management strategies are developed?* Answering this question, strategies are developed in the following steps

- Identifying transport problems.
- Selecting feasible measures corresponding to transport problems in the first matrix.
- Determining supportive systems for measures.
- Pinpointing requirements for actions.
- Formulating strategy by combining the three steps above and results shown as a strategy mask.

This process is fundamental to selecting feasible measures and to developing a transport demand management strategy in chapter 5. This section also discusses the assessment and optimisation of strategies which can be used after implementing transport demand management measures and strategies.

To ensure smooth implementation of transport demand management measures and strategies, the roles of stakeholders are reviewed. The role of the government: policymakers and executive authorities, is most important because they decide which policy, measures, and strategy are to be applied. They are responsible for planning the implementation process and for distributing the funds invested in the plan. They can influence public transport providers through their policies. They plan implementation awareness strategies to encourage travellers to change their behaviour. A secondary supporting role is played by public transport providers. Operators can improve public transport systems with the aim of realising higher safety, reliability, comfort, and other factors which attract more passengers. Travellers make their choice. Hence, **raising the awareness of travellers about transport problems as well as the benefits of public and active transport, plays an especially important role in acquiring transport demand management goals and objectives**.

To answer question *Q6: How is the status quo of transport and health impacts in Hanoi, Vietnam?* The first section of **chapter 5** is a brief review of the socioeconomic characteristics of Hanoi. This provides an overview of the urbanisation of the city. The next section presents the status quo of the transport system of Hanoi. This explains how urbanisation influences the transport system. Hanoi is a big city with a high density of population in the inner city, however, **there is a lack of road infrastructure. In fact, the road transport system does not keep up with the rise in demand.** The absence of an urban railway system and active transport facilities limits mobility options. This is the main cause of the exponential growth in numbers of private vehicles, particularly motorcycles. Motorcycle use accounts for approximately 80% of the passenger service market in Hanoi.

The next section presents transport planning for Hanoi and shows the road infrastructure and parking spaces that will be provided in the future. **Public transport systems such as urban railway, bus services and taxi services will be offered in the future. Park & Ride stations will integrate with planned metro lines.** However, in transport planning for Hanoi, **active transport is receiving less attention.**

With the transport service planned for Hanoi, the transport supply will be increased. However, **if it does not change the private mode choice behaviour, transport supply will still not be able to keep up with transport demand**. In order to change transport mode choice behaviour, **it is first**

necessary to understand the factors influencing transport mode choice behaviour. Also, **applying transport demand management measures and strategy affects traveller behaviour.**

The next section describes the status of health impacts in the case study of Hanoi, Vietnam. It reveals that health impacts related to transport in Hanoi such as air pollutants, noise pollution, traffic accidents, and psychological stress are the most negative health impacts. In the case study of Hanoi, air pollutants constitute the most significant negative health impacts. Particulate matters PM_{10}, and $PM_{2.5}$ exceed Vietnam national standards. Hanoi is in the top ten in the world, and is 6th in the list of most polluted regional cities in Southeast Asia. **The main cause of this situation is the exponential growth in the number of private vehicles, particularly motorcycles. This same cause is responsible for noise pollution, traffic accidents and psychological stress.** In a brief conclusion, problems have been identified relating to private vehicles, public transport, non-motorised transport, and negative health impacts in the case study of Hanoi.

Next to answer question *Q7: How do health impact awareness and other factors affect mode choice behaviour in Hanoi, Vietnam?* Section 5.2 starts with presenting suitable methods and collecting data. The survey method and process of collecting data are described. The next stage develops a hybrid choice model which can be used to answer question *Q7*. **The results of model confirmed that the model development process is possible to develop mode choice model**. **Hybrid choice model is suitable to analyse mode choice behaviour.** The model reveals that mode choice behaviour is not only impacted by observable factors but is also affected by latent variables such as reliability, flexibility, comfort, convenience and health impact awareness. **Particularly, the results illustrate that health impact awareness is an important influencing factor of mode choice behaviour. Hence raising health impact awareness is effective measures to change mode choice behaviour.**

In this section also are created three scenarios which analyse the change of transport mode choice behaviour with changing travel cost for bus users and changing travel time for private car users. **This shows that transport demand management measures and strategies can be used to affect these influencing factors**. From this, the behaviour of travellers can be changed toward choosing more healthy and user-friendly transport modes.

In order to influence traveller mode choice behaviour, section 5.3 selects suitable transport demand management measures, and develops transport demand management strategies. From the problem analysis in section 5.3.1, section 5.3.2 addresses research question *Q8: Which transport demand management measures are suitable for the case study of Hanoi, Vietnam?* With the health impact problems presented, transport demand management measures are selected in the following steps.

- First, the list of traffic management and transport demand management measures are identified. This step is done in chapter 4.
- Second, eliminating measures that overlap.
- Third, transport demand management measures are distilled from the list in step 2. In chapter 5, several measures which are already published in Hanoi transport planning will not be considered in this step.
- Finally, selecting transport demand management measures in relation to defined problems of the case study Hanoi, Vietnam.

In implementing the four steps above, there are four groups of measures: individual motorised transport measures, public transport measures, non-motorised transport measures, and raising awareness measures. **Connecting directly appropriated measures to problems is feasible for any case study including Hanoi.** For each group of measures, systems for implementation and requirements are identified. This is fundamental to developing transport demand management strategies in the next section. **The strategies with measures, supportive systems and requirement ensure the success of transport demand management.**

Section 5.3.3 of chapter 5 answers research question *Q9: Which transport demand management strategies can be implemented to change transport mode choice behaviour for the case study of Hanoi, Vietnam?* This section applies the German method to develop transport demand management strategies. Formulation of strategies involves a combination of problems, measures, supportive systems, and requirements. This combination creates strategy masks which are the final products of strategy development. Four strategies are established in this section: for individual motorised transport, public transport, non-motorised transport, and raising awareness. To ensure efficiency of strategies, the responsibilities of stakeholders to implement these strategies are also discussed. In order to achieve goals and objectives, the combination of strategies must be considered. The raising awareness strategy is the most important in supporting the other strategies. German method is successful to develop traffic management strategies in several case study, however, with the case of Hanoi, **it is the first time to be applied for transport demand management.** It is expected that **the negative health impacts of transport in case Hanoi will be reduced and the positive health impacts will be increased.**

6.2 Major conclusions, observations and findings

Major conclusions, observations and findings are presented below.

- **Studying on health impacts of transport should be encouraged in developing countries**.

  The economic development has received more attention than human health improvement in developing countries. Hence, there is lack of research on health impacts in these countries. Accordingly, the worse level of negative health impacts is observable in these countries compared to developed countries. Encouraging research projects on health impacts, particularly in transport might be helpful to solve these problems.

- **Research on the change of transport demand plays a pivotal role in increasing positive health impacts and reducing negative health impacts of transport.**

  Although, long periods of investment aim at providing more infrastructure in many developed countries, transport demand has still surpassed transport supply. Therefore, the change of transport demand has received more attention. In developing countries, focusing on the change of transport demand is more meaningful for three reasons. Firstly, developing countries have restriction of development space and limited financial resources. Secondly, developing countries are facing higher level of negative health impacts. Thirdly, the main cause of negative health impacts in developing countries is the dramatic increase of private vehicles. Hence, the change of transport mode choice behaviour can reduce negative health impacts and support human health.

- **Private vehicles are main cause of the negative health impacts. At the same time, public transport and active transport support human health. Hence changing transport mode choice behaviour properly can reduce negative health impacts and increase positive health impacts.**

  In order to change transport mode choice behaviour, it is needed to implement two phases: that is to analyse influencing factors of mode choice behaviour and implement transport demand management.

- **Several studies demonstrated that mode choice behaviour is affected not only by observable factors but also latent variables. This study shows that hybrid choice model is the most suitable to incorporate both observable factors and latent variables.**

  Literature review shows that traditional discrete choice model is applied to analyse the effect of observable factors while the psychological model is applied to analyse psychological factors such as attitude and perception of travellers. Mode choice behaviour is affected by both observable factors and latent variables. Hence, hybrid choice model is the most suitable model to incorporate both group of factors.

- **Results of this study confirm that seven observable factors: Income, age, gender, having children, education and five latent variables: Reliability, flexibility, comfort, convenience, and health impacts influence the mode choice behaviour significantly. Health impacts awareness is added to the model as a novel latent variable.**

  Although health impact awareness is effective on mode choice behaviour of travellers, it is limited number of studies consider health impact awareness as an influencing factor. The result of this study confirms that health impact awareness is also a significant influencing factors. Hence, raising health impact awareness can change mode choice behaviour of travellers.

- **In order to achieve health impact improvement by changing transport mode choice behaviour, consideration of health impacts in transport demand management is needed.**

  The effectiveness of applying transport demand management in reducing negative health impacts and increase positive health impacts at developed countries is valuable lesson for developing countries.

- **From the list of transport demand management measures, the pricing measures should have more priority to apply in developing countries.**

  There are some reasons why pricing measures should be applied for developing countries. Firstly, they are the most effective mean of changing transport mode choice behaviour. Secondly, these measures generate revenue for transport financial budget. Finally, the barriers to implement pricing measures are now removed by the development of technology.

- **This study suggests that German method to develop transport demand management strategies should be applied in developing countries.**

  The German method develops strategies with measures, supportive systems and requirement, which ensure the effectiveness of transport demand management.

- **For the case of Hanoi, this study proposes four main strategies: strategy for individual motorised transport, strategy for public transport, strategy for non-motorised transport and strategy for raising awareness.**

  Strategy for individual motorised transport aims at reducing private vehicle use while strategies for public transport and non-motorised transport attract more users. Raising awareness supports the effectiveness of other strategies, particularly for the case Hanoi.

- **Combination of strategies is more effective in changing transport mode choice behaviour.**

  Simulation the change of transport mode choice behaviour demonstrate a combination of strategies lead to the more change in reducing private vehicles use and increase public transport use and increasing public transport use in the case of Hanoi.

6.3 Limitations

Limitations are an issue which cannot be avoided in any study. However, limitations yield opportunities for further research. This section discusses some main limitations.

Limitation of research on health exposure of motorcyclists

As seen in the literature review in chapter 2, there are several studies on health impacts, but there is a lack of research on health impacts in developing countries, particularly in motorcycle dependent cities. Although there are numerous studies of the health exposure of pedestrians, cyclists, drivers of private cars and passengers on public transport, but not many on the health exposure of motorcyclists. However, research on health exposure of motorcyclists was beyond the scope of this study.

Limitations of model development

The approaches which are used to develop models encounter different limitations. In this study, the disaggregated approach is employed. The limitations of the disaggregated approach relate to data sampling, factors in the model and estimation of results.

Since the research financial budget and time are limited, modellers cannot collect data from all individuals in the population. Therefore, modellers must use data from a representative sample population. Statistical tests are used to identify the sample size needed to interpret the whole population. Although samples in this study confirmed trends reports in the literature, the number of individuals in the sample was small. With a bigger sample size, the model can represent the whole population more precisely.

This study reviews previous studies and selects all factors which have already been used to develop models. In addition to examining selected factors from previous studies, this study considers a novel factor: the health impact awareness of travellers. However, this does not mean that all possible influencing factors have been taken into consideration.

There are several software packages which can be used to estimate the model. However, this study only uses two packages in R-Programming and R-studio.

The developed hybrid choice model can be applied in any case study but the groups of travellers are different depending on the case study. The circumstances of the case study of Hanoi includes five groups of travellers: private car users, motorcyclists, bus users, bicyclists and e-bike users. These circumstances will be changed in the future when some metro lines are operated. Then, the number of groups of travellers will be changed. This will lead to a modification in input data and a different in the results of the model. To ensure a more precise description of the status quo of mode choice behaviour, modellers have to develop a new hybrid choice model with a new data sample.

Limitations of implementing transport demand management

This study selects suitable transport demand management measures, then develops strategies to affect the mode choice behaviour of travellers. However, these measures and strategies have not been employed, hence it is difficult to assess their effectiveness.

Transport demand management has been implemented in developed countries over a long period, but it is not receiving the attention of authorities in developing countries. The absence of a uniform policy on transport demand management restrains the implementation process.

The financial budget is also a restriction on employing transport demand management in developing countries, particularly in the case study of Hanoi. Since supportive systems are high technology devices, the cost for these systems is really higher for a developing countries.

6.4 Future scope of work for the case study of Hanoi

From the limitations presented above, this section makes some further study and the implementation of transport demand management.

There should be more encouragement of health impacts studies in developing countries. This should raise the awareness of scientists, policymakers, residents, and other stakeholders. In particular, the health exposure of motorcyclists is a very attractive subject for researchers.

Since circumstances can change in the future, for example with the increase in the number of groups of users, the hybrid choice model should be adjusted accordingly. Hopefully, this model will receive more attention from the authorities. Authorities could provide bigger budgets to enrich data samples with more respondents in larger survey areas. Then the model will be more precise and better represent the transport mode choice behaviour of the case study. By using precise results, scientists and policymakers will be able to analyse more accurately the influencing factors.

To ensure the effectiveness of implementing transport demand management, there are some noteworthy issues. First and foremost, awareness of health impacts needs to be increased in both residents and policymakers as well as in other stakeholders. Secondly, policymakers should publish a uniform policy on health impacts and transport demand management. Thirdly, the responsibility of stakeholders should be clarified in regulations which support a better implementation process.

Finally, after implementing new measures in transport demand management, there is a need for a quantitative assessment of their effectiveness.

List of abbreviations

AHP	Analytical Hierarchy Process
CNG	Compressed Natural Gas
EU	European Union
FGSV	Forschungsgesellschaft für Strassen – und Verkehrwesen
FTDM	Freight Transport Demand Management
GDP	Gross Domestic Product
GHG	Greenhouse Gas
IST	Intelligent Transport System
MIMIC	Multiple Indicator Multiple Cause
O-D	Origin-Destination
RUM	Random Utility Maximisation
TDM	Transport Demand Management
TMS	Traffic Management Strategies
TRANS-TOOLS	TOOLS for Transport Forecasting And Scenario testing
TSP	Total Suspended Particles
UN	The United Nation
US	The United States of America
VND	Vietnam Dong
VOC	Volatile Organic Compounds
WHO	World Health Organisation

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Appendices

Appendix 1: List of traffic management measures

Components	Type	Measures
Multidisciplinary	Land-use planning	Type, degree and distribution of use
	Agreements on use	Agreements to influence travel demand
		Agreements to influence modal choice
		Agreements to eliminate traffic peaks
	Marketing and awareness raising	Public awareness concepts
		Traffic education and driver training
		Training from experts
	Measures in the political and legal framework	Organisational measures
		Adaptation of traffic laws
		Enforcement of traffic regulations
		Others
Supply of transport infrastructure	Facilities for public transport	Suburban train
		Tramway and bus
		Other public transport
	Facilities for individual transport	Extension and maintenance of the street network
		Parking space
	Facilities for pedestrians and cyclists	Walkway network
		Bicycle network
	Other traffic facilities	Park+Ride facilities, Park+Share facilities
		Facilities for freight traffic
Traffic operations	Financial and administrative measures for road traffic	Parking management
		Access control
		Special lanes/ Slot management
		Mobility pricing/ Road pricing
		Oil tax and vehicle tax
		Monitoring
		Others
	Collective information and collective control of road traffic	Traffic signal control
		Intersection control
		Road section control
		Lane signalling
		Network control
		Mobility service centres
		Information systems with public devices
	Individual information and individual control of vehicles while driving	Dynamic individual guidance of vehicles
		Intermodal individual guidance and information systems
		Individual speed control
		Virtual chained vehicles, convoy trips
		Automatic lateral guidance of vehicles
		Car2car/Car2Infrastructure communication
		Driver assistance systems
	Management of public transport	Schedule and fare arrangement
		Computer-aided operator systems
		Prioritization measures
		Assurance of connections
		Systems for payment and ticketing
		Avoidance and removal of disturbances
		Passenger information systems
	Freight and fleet management	Freight exchange and City logistics
		Innovative concepts

		Fleet management systems
	Organisation of vehicle usage	Car sharing
		Car pooling
	Management approaches	Accident and incident management
		Road works management
		Management of large loads
		Operation service management
		Traffic management during big events
		Information management
		Quality management
		Strategy planning and dynamic strategy management

Source: Boltze (2016)

Appendix 2 Classification of travel reduction measures

Measure	Effect					
	Switching			Substition		
	Mode	Destination	Time	Linking trips	Technology	Modification
Capacity Management						
Freeze on new road infrastructure	x					
Road capacity restraint/throttling	x	x				
Integrated planning				x		
Pricing/Taxation						
Road pricing location	x	x				
Road pricing by time	x		x			
Fuel pricing	x					
Information pricing		x				
Parking charges, by location or time	x	x	x			
Car ownership taxation	x					
Tax concessions	x					
Pollution pricing	x	x	x			
Commuted payments	x					
Land Use Planning						
Urban concentration		x		x		
Mixed use developments		x		x		
Development at public transport modes	x	x				
Design of new developments to facilitate walking/cycling	x	x				
Design of new developments to provide access to transport services	x	x				
Communications and Technology						
Teleworking/telecommuting					x	
Teleshopping/telebanking					x	
Telematics/informatics-providing information remotely					x	
Telematics-route planning and electronic guidance						x
Telematics-VMS suggesting switching to park and ride	x					
Electronic freight dispatching						x
Vehicle technology-intermodally	x					
Demand-responsive transport	x			x		
Provision of non-telematics travel information	x					
Policy measures						
Public transport deregulation	x					
Company car policy	x					
Lift sharing/carpooling schemes				x		
Company working hours policy			x			
Company plans to encourage use of alternative modes	x					
Park-and-ride	x					
Encourage opportunities for intermodality	x					
Enforcement of road traffic regulations	x					
Return goods optimization (freight)				x		
Use of alternative modes by freight companies	x					

Restriction of trucking licences	x					
Physical Measures						
Public transport priority	x					
Public transport road space	x					
Cycle priority	x					
Cycle road space	x					
Pedestrian priority	x					
Pedestrian road space	x					
Carpooling priority road space (HOV schemes)				x		
Carpooling road space				x		
Traffic calming-discouraging private car use	x					
Subsidies and Spending						
Carpooling subsidies				x		
Cycle subsidy/investment in cycle networks	x					
Walk subsidy/investment in cycle networks	x					
Public transport subsidy-operators	x					
Public transport subsidy-individual/groups	x					
Public transport capacity investment	x					
Location/Time/User restrictions						
Area access controls by user-e.g., resident' access only, weight restrictions, total vehicle bans	x					
Area access controls by time e.g., access only in non-peak periods		x				
Restriction on city centre parking	x	x				
Restriction on company parking	x					
Time and user restrictions on public parking	x		x			
Public awareness						
Media campaigns to promote walking/cycling/public transport	x					
Increase awareness of public transport services	x					
Other						
Home delivery of goods/services						x
Car sharing/ subscription car rental						x
Improving access to public transport	x					
Urban freight distribution centres-small loads gathered into one lorry for delivery to city centre				x		x
Freight logistics schemes-co-ordination of freight distribution trips between companies				x		x

Source: Marshall et al. (1997)

Appendix 3 Group of transport demand management measures

Improved Transport Options	
Address Security Concerns	Strategies for improving personal security.
Alternative Work Schedules	Flexible time, Compressed Work Week (CWW), and staggered shifts.
Bus Rapid Transit	Bus Rapid Transit (BRT) systems provide high quality bus service on busy urban corridors.
Cycling Improvements	Strategies for improving bicycle transport.
Bike/Transit Integration	Ways to integrate bicycling and public transit.
Carsharing	Vehicle rental services that substitute for private vehicle ownership.
Flexible time	Flexible daily work schedules.
Guaranteed Ride Home	An occasional subsidized ride home for commuters who use alternative modes.
Individual Actions for Efficient Transport	Actions that individuals can take to increase transport system efficiency.
Light Rail Transit	Light Rail Transit (LRT) systems provide convenient local transit service on busy urban corridors.
Mobility Hubs	Transportation terminals designed to integrate diverse travel options and support services.
Nonmotorized Planning	Planning for walking, cycling, and their variants.
Nonmotorized Facility Management	Best practices for managing nonmotorized facilities such as walkways, sidewalks and paths.
Pedways	Indoor urban walking networks that connect buildings and transportation terminals.
Public Bike Systems	Automated bicycle rental systems designed to provide efficient mobility for short, utilitarian urban trips.
Ridesharing	Encouraging carpooling and vanpooling.
Shared Mobility Services	Ride hailing, ridesharing, carsharing and bike sharing services.
Shuttle Services	Shuttle buses, jitneys and free transit zones.
Small Wheeled Transport	Accommodating wheeled luggage, skates, scooters and handcarts.
Transit Station Improvements	Describes ways to improve public transit stop and station waiting conditions.
Taxi Service Improvements	Strategies for improving taxi services.
Telework (Telecommuting, Distance-Learning, etc.)	Use of telecommunications as a substitute for physical travel.
Traffic Calming	Roadway designs that reduce vehicle traffic speeds and volumes.
Transit Improvements	Strategies for improving public transit services.
Transit Examples	Describes successful transit programs.
Universal Design (Barrier Free Planning)	Transport systems that accommodate all users, including people with disabilities and other special needs
Walkability Improvements	Strategies for improving walking conditions.
Incentives To Use Alternative Modes and Reducing Driving	
Carbon Taxes	Special taxes based on fuel carbon content intended to encourage energy conservation and climate change emission reductions.
Commuter Financial Incentives	Parking cash out, travel allowance, transit and rideshare benefits.
Congestion Pricing	Variable road pricing used to reduce peak-period vehicle trips.
Complete Streets	Designing Roads for Diverse Modes, Users and Activities
Distance-Based Pricing	Vehicle fees and taxes based on a vehicle's mileage.
Fuel Taxes	Increasing fuel taxes to achieve TDM objectives.
HOV (High Occupant Vehicle) Priority	Strategies that give transit and rideshare vehicles priority over other traffic.
Multi-Modal Navigation Tools	Describes wayfinding resources and other multi-modal navigation tools.
Parking Pricing	Charging motorists directly for parking.
Pay-As-You-Drive Insurance	Converting vehicle insurance premiums into distance-based fees.
Road Pricing	Congestion pricing, value pricing, road tolls and HOT lanes.
Road Space Reallocation	Roadway design and management practices that favor efficient modes.
Speed Reductions	Strategies to reduce traffic speeds.
Transit Encouragement	Strategies for encouraging public transit use.

Vehicle Use Restrictions	Limiting vehicle traffic at a particular time and place.
Walking and Cycling Encouragement	Strategies for encouraging nonmotorized transportation.
Parking and Land Use Management	
Bicycle Parking	Bicycle racks, lockers and changing facilities.
Car-Free Planning	Strategies to reduce automobile travel at particular times and places and create pedestrian oriented streets.
Strong Commercial Centres	Creating vibrant downtowns, business districts, urban villages, and other mixed-use activity centres.
Connectivity	Creating more connected roadway and path networks.
Land Use Density and Clustering	Locating common destinations close together to increase accessibility and transport diversity.
Location Efficient Development	Development that maximizes accessibility and affordability.
New Urbanism	Accessible, liveable community design.
Parking Cost, Pricing and Revenue Calculator	Excel spreadsheet calculates parking facility costs, prices and revenue.
Parking Management	Strategies for more efficient use of parking.
Parking Management: Strategies, Evaluation and Planning - *Comprehensive*	This report provides comprehensive guidance on parking management (PDF format).
Parking Pricing	Charging motorists directly for using parking facilities.
Parking Solutions	Comprehensive menu of solutions to parking problems.
Parking Evaluation	Guidelines for evaluating parking problems and solutions.
Shared Parking	Sharing parking facilities among multiple users.
Smart Growth	Land use practices to create more accessible, efficient and liveable communities.
Smart Growth Reforms	Policy and planning reforms that encourage more accessible land use development.
Smart Growth Reforms - *Comprehensive*	This report provides detailed information on Smart Growth policy and planning reforms. (PDF Format)
Streetscape Improvements	Various ways to improve urban street design.
Transit Oriented Development (TOD)	Using transit stations as a catalyst to create more livable communities.
Land Use Impacts on Transport	Describes how land use factors such as density, mix and regional accessibility affect travel behavior.
Land Use Impacts on Transport - *Comprehensive*	This comprehensive report provides detailed information on how land use factors affect travel behaviour
Policy and Institutional Reforms	
Asset Management	Policies and programs to preserve the value of assets such as roadways and parking facilities.
Car-Free Planning	Strategies to reduce driving at particular times and places.
Change Management	Ways to build support for institutional change.
Comprehensive Market Reforms	Policy changes that result in more efficient transport pricing.
Context Sensitive Design	Flexible design requirements to reflect community values.
Contingency-Based Planning	Planning that deals with uncertainly by identifying solutions to potential future problems.
Institutional Reforms	Creating organizations that support efficient transport.
Least Cost Planning	Creating an unbiased framework for transport planning.
Operations and Management Programs	Programs that encourage more efficient use of existing roadway systems.
Prioritizing Transportation	Principles for prioritizing transportation activities and investments.
Regulatory Reform	Policy changes to encourage transport service competition, innovation and efficiency.

Source: Victoria Transport Institute (2020)

Appendix 4 Urban area, transport system and transport planning of Hanoi

Appendix 4.1 List of road planning in Hanoi until 2030

TT	Route Planning	Scales	
		Length (km)	Width (m)
A	**Until 2020**		
I	***External road***		
1	Expressway Phap Van -Cau Gie	25	90
2	Expressway Hanoi-Lang Son	1	100
3	Highway No.1	25	46
4	Highway No.32	40	35
5	Highway No.2	2	35
6	Highway No.21B	42	35
7	Highway No.23	1	35
8	Highway No.2C	1	35
9	Highway No.5		
II	***Road routes outside urban areas***		
1	Ring road No.4 -Son tay	20	40
2	Southern economic development route	35	40
3	Do xa - Quan Son	26	37
4	Chuc son-Mieu mon- Huong Son	42	27
5	Provincial road No.411: Dong Bang -Co Do	8	21
6	Provincial road No.412: Tay Dang -Dong Lau	5	21
7	Provincial road No.411C: Dong Bang-Tong Dat	7	21
8	Provincial road No.413: Bat Bat- Son Tay	23	21
9	Provincial road No.414B: Ba Trai- Tan Linh	6	21
10	Provincial road No.415: Da Chong -Che	12	21
11	Provincial road No.412B: Suoi Hai-Huu Hong-Viet Tri-Ba Vi	21	21
12	Provincial road No.414: Son Tay – Tan Linh	16	21
13	Provincial road No.427: Hong Van -Kim Bai- Xuan Mai	30	23
14	Provincial road No.423: An Thuong-Dong Quang- Xuan Mai	18	21
15	Provincial road No.429A Mieu Mon- Southern of Hanoi	20	21
16	Provincial road No.416: Van Hoa-Cung Son-Huu Hong	16	21
17	Provincial road No.428: Van Dinh – Quang Lang	15	21
18	Provincial road No.428B: Tri Thuy-Minh Tan	11	21
19	Provincial road No.424: Quan Son-Te Tieu	10	21
20	Provincial road No.426: Quan Xa- Thai Bang	10	21
21	Provincial road No.420: Lien Quan – Hiep Thuan	9	21
22	Provincial road No.446: Hoa Lac- Xuan Mai	6	21
23	Chua Huong – Bai Dinh	17	21
III	***Urban Expressway***		
1	Ring road No.4:	18	120
2	Ring road No.3		
	Noi Bai -Quang Minh	4	120
	Quang Minh - Thang Long Bridge	9	68-150
	Thăng Long Bridge – Mai Dich	7	57-85
	Co Bi – Viet Hung	15	68
3	Expressway Phap Van-Cau Gie	8	90
4	Expressway Hanoi-Hai Phong	7	100
5	Expressway Hanoi-Lang Son	1	100
IV	***Urban Road***		
1	Ring road No.2		
-	Vinh Tuy -Nga Tu Vong	4	53,5-60
-	Cau Giay-Xuan La	6	58

TT	Route Planning	Scales	
		Length (km)	Width (m)
-	Xuan La - Nhat Tan	4	64
-	Cau Chui -Sai Dong	7	57,5-60
2	Hanoi- Thai Nguyen - Bac Thang Long - Noi Bai	14	68
3	Quang Minh- Thuong Cat Bridge – Dai Lo Thang Long		
	Quang Minh - Thuong Cat Bridge	16	60
	QL32 – Dai Lo Thang Long	6	60
	Van Phu – Ngoc Hoi	13	80
4	Giai Phong – Ngoc Hoi – Ring road No.	13	46
5	Ring road No.2– Ring road No.3 – Ring road No.4		
	Ring road No.2 – Ring road No. 3	3	30
	Ring road No.3 – Ring road No.4	8	53,5-60
6	Hong Ha Bridge - Thanh Tri Bridge	29	40-60
7	Van Cao – Ring road No.3.5 - Ring road No.4		
	Van Cao – Ring road No.3.5	9	50-53,5
	Ring road No.3.5 – Ring road No.4	5	350
8	Huu Song Hong – Tran Khat Chan – Dai Co Viet – Kim Lien – O cho Dua – Cau Giay – Ring road No.4		
9	Ho Tay-Lieu Giai-Nguyen Chi Thanh-Tran Duy Hung- Ring road No.3	5	50
10	Xom Tho – Me Linh – Ring Road No.4	9	68-100
11	National Highway No.5	8	60
12	Vinh Ngoc - Van Tri -Thuong Cat	8	50-72,5
13	Nhat Tan - Noi Bai Airport	16	80-100
14	TC20: Trục Quang Minh – Chi Đông – Vành đai 4	8	68
V			
1	Linh Nam – Kim Dong – Dinh Cong – Nguyen Trai – Yen Hoa – Xuan Dinh – Phu Thuong	20	40-50
VI	***Inter-area road***		
1	Phu Thuong – Thuong Cat -Lien Hong- Duc Thuong -An Khanh	27	40
2	An Khanh – Tay Mo	3	30-40
3	Tay Mo - Duong Noi - Van Khe	5	30-40
4	La Phu - Van Phuc - Xa La	11	25-30
5	Nhat Tan -Yen Phu – Tran Kha Chan	10	45-50
6	Cau Dien – Dich Vong	4	40
7	Huu Hong – Hung Vuong	2	20-26
8	Hung Vuong - Van Cao	2	54
9	Phung Hung - Le Duan		
-	Phung Hung - Tran Hung Dao	2	21
-	Tran Hung Dao - Le Duan	1	42
10	Quang Minh - Bac Hong – Kinh Noi	8	40
11	Co Bi - Trau Quy – Duong Xa	6	22-30
12	Bo De – Cu Khoi	5	40
13	Dong Du - Co Bi	5	40
B	**Until 2030**		
I	***External Route***		
1	Ring road No.5	48	120
2	Ring road No.4	53	120
3	Hoa Lac – Hoa Bih	12	100
4	Hanoi – Ha Long	16	100
5	Dong Mo -Song Da	19	100
6	Tay Bac – National highway No.5	35	100
7	National Highway No.3	13	35
8	National Highway No.6	22	35

TT	Route Planning	Scales	
		Length (km)	Width (m)
9	National Highway No.21	46	35-80
10	Ring road No.4 – Hoa Lac	25	50
11	Ha Dong - Xuan Mai	20	40
12	Southern route – Nothern route	60	42
13	Southern economic development route	35	40
14	Chuc Son - Mieu Mon - Huong Son	42	27
15	Tien Thang – Chu Phan	11	21
16	Tam Bao – Thach Da	7	21
17	Huu Hong - Quoc Oai – Chuc Son - Tran Dai Nghia – Huong Son	67	21
18	Thai Hoa -Trung Vuong -Tho Xuan - Hong Ha Bridge	54	21
19	Ring road No.4 – Bac Giang	18	23
III	***Urban Expressway***		
1	Ring road No.4		
-	National road No.6 – National road No.1	16	120
-	National road No.1 – Me So Bridge	4	120
-	National road No.32 - National road No.2	15	120
2	Ring road No.3		
	Co Bi – Viet Hung	15	68
IV	***Urban Route***		
1	Nguyen Trai – Ring road No.4	10	56-65
2	Thuong Cat – Ta Hong – Vinh Tuy – Thanh Tri	28	40-60
3	Vinh Tuy - Giang Bien - Ninh Hiep	7	40-81
4	Chuong Duong – Nguyen Van Cu- Ngo Gia Tu – National Highway No.1 – Ring road No.3	10	42-48
5	Tu Lien – Co Loa – Ring road No.3	8	60
6	Vinh Thanh - National Highway No.3 - Phu Lo	10	50-71
7	Bac Thang Long – Noi Bai – Ha Long	12	89
V	***Urban route***		
1	Phu Do – Yen Hoa – Ring road No.2	4	50
2	Thuong Cat – Dai Mo - Ha Dong	14	28-50
3	An Thuong – Dai Mo – Ha Dong – Van Dien	19	35-50
4	Tan Lap – An Khanh – La Phu	16	30-50
5	Co Bi – Viet Hung - Co Loa - Van Noi - Tien Phong - Dai Thinh	33	40-50
6	Co Loa – Viet Hung – Xuan Thu -Soc Son	14	40-50
VI	***Ring road***		
1	Ring road No.2		
	Vinh Tuy – Nga Tu Vong	4	19
	Nga Tu Vong – Nga Tu So	2	19
	Nga Tu So – Cau Giay	4	19
2	Ring road No.2 – Le Trong Tan – Ring road No.3 – Ring road No.4	3	19
3	Phu Do – Yen Hoa - Ring road No.2	4	19
	Nam Thang Long – Thanh Xuan – Phap Van	19	24
VII	***Inter-area road***		
1	Thuong Cat – Duc Thuong – Son Dong	9	50
2	Duc Thuong – Phu Dien – Xuan La	13	40
3	Duc Giang – Kim Chung – Son Dong	9	30
4	Kim Chung – Cat Que	5	30
5	Son Dong – Xuan Phuong – My Dinh	10	40-50
6	An Khanh – Xuan Phuong – Minh Khai	9	40
7	An Khanh – La Phu – Phu Luong	12	40-50
8	An Khanh – Tay Mo	3	39-40
9	Thuy Phuong – My Dinh – Me Tri - Van Khe	11	40-120

TT	Route Planning	Scales	
		Length (km)	Width (m)
10	La Phu – Ha Cau	4	40
11	National Highway No.31B	3	35
12	Phu Lam – Phu Dien	5	24-27
13	Kien Hung – Cu Khe	5	30
14	Cu Khe - My Hung	5	40
15	Ngoc Hoi – Dai Ang – Cu Khe	9	30-50
16	Ngoc Hoi - Phu Xuyen	11	40
17	Van Dien – Vinh Quynh – Dai Ang	5	25
18	Ngoc Hoi – Nhi Khe	4	25
19	Dong Ngac -Co Nhue – Cau Dien – Me Tri	12	12-17,5
20	Thuy Phuong – Phu Thuong	6	40-64
21	Xuan Dinh – Nghia Tan – Dich Vong	5	40
22	Trang Tien – Trang Thi – Tran Phu – Kim Ma – Voi Phuc	6	20-58,5
23	Tran Hung Dao – Hanoi Main Station – Hao Nam - Giang Vo	7	30
24	O Cho Dua – Nguyen Thai Hoc	4	29
25	Ton That Tung – Pham Ngoc Thach – Hanoi Main Station	3	30
26	Phung Hung – Le Duan	1	34
27	Hang Bai – Pho Hue – Bach Mai – Truong Dinh	6	17-40
28	Nguyen Khoai – Yen So	5	30-40
29	Thanh Tri -Yen So	4	40
30	Kim Nguu – Nguyen Tam Trinh – Cang Khuyen Luong	7	40-70
31	Bac Hong – Phu Minh	2	40
32	Quang Minh – Dai Thinh	5	48
33	Thanh Lam – Ap Tre	5	24
34	Thanh Lam – Tien Phong	7	24
35	Ap Tre – Tien Phong – Yen Nhan	7	48-50
36	Tien Phong – Dai Mach	4	48-50
37	Nam Hong – Kim No – Thang Long Bridge	5	30-40
38	Tien Phong – Kim No – Hai Boi	8	40-50
39	Nam Hong – Tien Duong	6	25-30
40	Nguyen Khe – Tien Duong – Le Phap	6	40
41	Xuan Non – Dong Anh – Lien Ha	8	40
42	Xuan Non – Nguyen Khe – Phu Cuong – Kim Hoa	17	40-50
43	Dong Anh – Thuy Lam	6	40
44	Vinh Ngoc – Xuan Canh – Dong Ngan	7	38-62
45	Phu Dong – Yen Vien – Viet Hung – Van Noi	22	25-40
46	Yen Thuong – Mai Lam - Dong Ngac	8	40
47	Mai Lam – Dong Ngan	5	30-52
48	Ngoc Thuy – Thuong Thanh	5	40
49	Dong Anh – Yen Vien – Duong Ha	12	30-50
50	Gia Thuy – Cang Gia Bien	4	30
51	Ngoc Thuy – Duc Giang – Co Bi – Kieu Ky	19	30-60

Source: Hanoi transport department (2019)

Appendix 4.2: Area and population in urban districts of Hanoi as of the year 2019

	District	Area (km^2)	Population (people)	Population density (people/km^2)
1	Ba Dinh	9.21	247100	26,830
2	Hoan Kiem	5.29	160600	30,359
3	Tay Ho	24.39	168300	6,900
4	Long Bien	59.82	291900	4,880
5	Cau Giay	12.32	266800	21,656
6	Dong Da	9.95	420900	42,302
7	Hai Ba Trung	10.26	318000	30,994
8	Hoang Mai	40.32	411500	10,206
9	Thanh Xuan	9.09	285400	31,397
10	Nam Tu Liem	32.19	236700	7,353
11	Bac Tu Liem	45.32	333300	7,354
12	Ha Dong	49.64	319800	6,442
	Total of 12 districts	***307.8***	***3,460,300***	***11,242***
	Hanoi	**3,358.6**	**8,054,000**	**2,398**

Source: Hanoi Statistical Office (2019)

Appendix 4.3 Descriptive information for road transport in 4 central districts

	District	Area (km^2)	Road area (m^2)	Road area/person (m^2/person)	Road density (km/km^2)	Ratio of land for traffic (%)
1	Hoan Kiem	5.29	910,714	6.18	10.34	17.22
2	Ba Dinh	9.21	1,177,670	5.21	6.54	12.73
3	Hai Ba Trung	10.09	859,554	2.91	4.51	8.52
4	Dong Da	9.95	989,045	2.67	4.49	9.93
	Average			**4.24**	**5.94**	**11.38**

Source: Hanoi Transport Department (2019)

Appendix 4.4 Descriptive information for road transport between ring roads No.2 and No.3

	Districts	Area (km^2)	Road area (m^2)	Road area/person (m^2/person)	Road density (km/km^2)	The ratio of land for traffic (%)
1	Hoang Mai	39.81	1,778,723	5.27	2.91	4.47
2	Thanh Xuan	9.08	1,110,094	4.94	5.26	12.23
3	Cau Giay	12.03	1,894,775	8.32	4.86	15.75
	Average			**6.06**	**3.64**	**7.85**

Source: Hanoi Transport Department (2019)

Appendix 4.5 Descriptive information for road transport outside ring road No.3

	Districts	Area (km^2)	Road area (m^2)	Road area/person (m^2/person)	Road density (km/km^2)	The ratio of land for traffic (%)
1	Dan Phuong	77.35	2,878,158	12.94	1.04	2.37
2	Hoai Duc	82.47	3,207,979	16.57	0.66	3.89
3	Ha Dong	48.34	1,234,264	5.32	1.31	2.55
4	Thanh Tri	62.93	2,001,396	10.09	1.77	3.18
5	Nam Tu Liem	75.33	3,899,272	9.88	0.46	5.18
6	Bac Tu Liem					
	Average			**11.39**	**0.67**	**3.82**

Source: Hanoi Planning Report (2019)

Appendix 4.6 Descriptive information of road transport north of Red River and south of Ca Lo River

	Districts	Area (km^2)	Road area (m^2)	Road area/person (m^2/person)	Road density (km/km^2)	Ratio of land for traffic (%)
1	Long Bien	59.93	2,527,548	11.13	2.44	5.7
2	Gia Lam	114.73	3,070,783	13.22	0.99	1.3
3	Dong Anh	182.14	4,929,350	14.76	1.15	2.2
4	Me Linh	142.26	3,162,411	16.39	0.83	1.8
	Average			**13.88**	**1.18**	**2.74**

Source: Hanoi Planning Report (2019)

Appendix 4.7 Descriptive information for road transport in rural areas of Hanoi

	Districts	Area (km^2)	Road area (m^2)	Road area/person (m^2/person)	Road density (km/km^2)	The ratio of land for traffic (%)
1	Ba Vi	424.03	4,992,250	20.20	0.32	1.1
2	Phuc Tho	117.19	2,878,158	17.95	1.14	2
3	Thach That	202.51	3,007,932	16.90	0.65	1.7
4	Quoc Oai	147.01	3,844,651	23.88	0.59	2.6
5	Phu Xuyen	171.1	3,035,840	16.72	0.58	1.6
6	Thuong Tin	127.39	3,295,820	14.93	0.79	1.8
7	My Duc	230.31	4,169,201	24.41	0.67	1.6
8	Ung Hoa	183.76	2,598,340	14.30	0.52	1.2
9	Thanh Oai	123.85	3,922,800	33.61	0.76	1.6
10	Son Tay	113.53	1,823,356	14.47	0.54	1
11	Chuong My	232.41	4,588,721	15.84	0.70	1.8
12	Soc Son	306.51	5,686,924	19.95	0.66	0.8
	Average			**18.91**	**0.61**	**1.84**

Source: Hanoi Planning Report (2019)

Appendix 4.8 Long-distance coach stations in Hanoi

	Name of station	Located district	Area (m^2)	Capacity (vehicle/day)
1	Giap Bat	Hoang Mai	36,480	1,829
2	My Dinh	Nam Tu Liem	32,780	1,829
3	Yen Nghia	Ha Dong	43,824	2,382
4	Gia Lam	Long Bien	11,827	905
5	Nuoc Ngam	Hoang Mai	17,867	664
6	Son Tay	Son Tay	5,356	391
	Total		**148,134**	**8,000**

Source: Hanoi Transport Department (2019)

Appendix 4.9 Commercial transport stations in Hanoi

	Located districts	Name of station	Area (m^2)
Stations			***57,400***
1	Bac Tu Liem	Xuan Phuong	2,900
2	Gia Lam	Yen Vien	6,500
3	Thanh Tri	Ngu Hiep	41,000
4	Hoang Mai	Thanh Tri	7,000
Parking spaces			***52,850***
1	Hoang Mai	Tam Trinh	1,000
2		Den Lu	4,600
3	Long Bien	Gia Thuy	1,800
		Long Bien	1,450
4	Thanh Tri	Lien Ninh	19,000
5	Dong Anh	Hai Boi	20,000
6		Doc Van	5,000
	Total		**110,250**

Source: Hanoi Transport Department (2019)

Appendix 4.10 Parking spaces in urban areas of Hanoi

	District	Area (m^2)	The number of parking spaces
1	Hoan Kiem	30,501	182
2	Hai Ba Trung	54,010	126
3	Ba Dinh	43,003	66
4	Dong Da	8,741	31
5	Tay Ho	1,659	8
6	Cau Giay	46,020	47
7	Thanh Xuan	28,878	48
8	Hoang Mai	20,052	17
9	Long Bien	368	3
10	Ha Dong	3,168	11
11	Nam Tu Liem	98,598	32
12	Bac Tu Liem	5,392	6
	Total	**340,390**	**577**

Source: Hanoi Transport Department (2019)

Appendix 4.11 The change in functions of long-distance coach stations

	Area (m^2)	Current Function	Planning Function
Gia Lam	14,500	Coach station Bus terminal	Public parking space Bus terminal
Giap Bat	36,500	Coach station Bus terminal	Public parking space Bus terminal
Nuoc Ngam	17,700	Bus terminal	Bus terminal Park & Ride station
My Dinh	34,200	Coach station Bus terminal	Park & Ride station Bus terminal

Source: Hanoi Planning Report (2019)

Appendix 4.12 Planning of seven new long-distance coach stations

	Area (m^2)	Functions
Noi Bai	100,000	Coach station Bus terminal
Dong Anh	53,000	Coach station Bus terminal
Co Bi	104,000	Coach station Bus terminal
Yen Nghia	70,000	Coach station Bus terminal
Phung	150,000	Coach station Bus terminal
West station	50,000	Coach station Bus terminal
South station	100,000	Coach station Bus terminal

Source: Hanoi Planning Report (2019)

Appendix 4.13 Urban railway planning of Hanoi

	Metro line	2020	2030
1	Ngoc Hoi – Yien Vien – Nhu Quynh		
	Ngoc Hoi – Yen Vien	26 km	
	Yen Vien – Nhu Quynh		10 km
2	Noi Bai - Nam Thang Long - Thuong Dinh - Buoi		
	Nam Thang Long - Thuong Dinh	18 km	
	Noi Bai – Nam Thang Long		18 km
	Thuong Dinh - Buoi		7 km
3	Cat Linh - Ha Dong	14 km	
4	Troi –Nhon - Hanoi railway stations – Yen So		
	Nhon – Hanoi railway stations	13 km	
	Troi - Nhon		6 km
	Hanoi railway stations – Yen So		8 km
5	Me Linh – Lien Ha		
6	Van Cao – Road belt 4 – Hoa Lac		
	Van Cao – Road belt 4	14 km	
	Road belt 4 – Hoa Lac		26 km
7	Noi Bai – Ngoc Hoi		43 km
8	Me Linh – Duong Noi		28 km
9	Son Dong – Duong Xa		12 km
	Monorail lines	**2020**	**2030**
1	Lien Ha - Tan Lap - An Khanh		11 Km
2	Mai Dich – Phu Luong		22 km
3	Nam Hong – Dai Thinh		11 Km

Source: Hanoi Planning Report (2019)

Appendix 4.14 Bus rapid transit lines planned in Hanoi

	Rapid transit bus lines	2020	2030
1	Kim Ma – Le Van Luong – Yen Nghia	14 km	
2	Ngoc Hoi – Phu Xuyen		27 km
3	Son Dong – Ba Vi		30 km
4	Phu Dong – Bat Trang – Hung Yen		15 km
5	Gia Lam – Me Linh		30 km
6	Me Linh – Yen Nghia – Lac Dao		53 km
7	Ba La – Ung Hoa		29 km
8	Ung Hoa – Phu Xuyen		17 Km

Source: Hanoi Planning Report (2019)

Appendix 5: Sample survey form

Part 1: Mode choice, travel cost and travel time for daily trip

1. Can you answer the following questions regarding your daily trip?

Origin address: ……………………………………………

Destination address: ……………………………………………

From house to parking (bus stop): ……. (km)

From original parking (bus station) to destination parking (bus stop): ……. (km)

From parking (bus stop) to destination: ……. (km)

2. Which mode of transport do you usually use for daily trip?

☐ Motorbike ☐ Bus ☐ Car ☐ E-Bike

☐ Bicycle ☐ Others: ………………………...

3. How much is your transport cost?

If commuter travel by private vehicle

Fuel consumption …………………………

Fuel cost: ………………………… (VND)

Parking fees: ………………………….(VND)

If commuter travel by public transport

Ticket:

☐ Monthly priority ticket on one-line ☐ Monthly priority ticket on multiple-lines

☐ Monthly non-priority ticket on one-line ☐ Monthly non-priority ticket on multiple-lines

☐ Ticket for one-way: ………………………...

4. How long do you spend on your daily trip:

By bus or combine

Walking (or first vehicle) time: ……………………. minutes

In-vehicle time: ……………………. minutes

Transfer and waiting time: ……………………. minutes

Egress time: ……………………. minutes

By another vehicle

Access parking time: ……………………. minutes

In-vehicle time: ……………………. minutes

Egress time: ……………………. minutes

Part 2: Assessment of reliability, flexibility, comfort, convenience and health impacts

Please rate each of these factors that may influence on your mode choice of transport

		Very important	Somewhat important	Median	Somewhat unimportant	Not important
1	**Reliability**					
	On time	☐	☐	☐	☐	☐
2	**Flexibility**					
	Change route easily	☐	☐	☐	☐	☐
	Change time easily	☐	☐	☐	☐	☐
3	**Comfort**					
	Comfort in vehicle	☐	☐	☐	☐	☐
4	**Convenience**					
	Ease of accessibility	☐	☐	☐	☐	☐
	Ease of transfer	☐	☐	☐	☐	☐
5	**Health impacts**					
	Air pollution	☐	☐	☐	☐	☐
	Noise pollution	☐	☐	☐	☐	☐
	Safety	☐	☐	☐	☐	☐
	Radiation (UV ray)	☐	☐	☐	☐	☐
	Psychological stress	☐	☐	☐	☐	☐

Part 3: Information of travellers

1. **What is your gender?**

☐ Male ☐ Female

2. **How old are you?**

☐ Under 23 years old ☐ 23-33 years old ☐ 34-44 years old

☐ 45-55 years old ☐ 55 years old later

3. **How much income per month do you get?**

☐ Under $5x10^6$ (VND) ☐ $5x10^6$ – $10x10^6$ (VND) ☐ $10x10^6$ (VND) - $15x10^6$ (VND)

☐ $15x10^6$ (VND) - $20x10^6$ (VND) ☐ Over $20x10^6$ (VND)

4. **Which level of education do you have?**

☐ High school ☐ Bachelor ☐ Postgraduate

5. **Do you have children?**

☐ Yes ☐ No

6. **Which vehicle do you have?**

☐ Bicycle ☐ Motorbike ☐ E-bike

☐ Car

Information of surveyor and respondents

Respondent name: ……………………………………………………………	Location: ...…………………………………
	Time: ………………………………………..
Phone number: …………………………………………	Name of surveyor: …………………………