Technische Universität München
Professur für Modellierung räumlicher Mobilität

MASTER’S THESIS

Evaluation of the Impact of Erding Ring Closure on Passenger Flows in Munich Region
Evaluierung der Auswirkungen des Erdinger Ringschlusses auf Passagierströme in der Region München

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MASTER'S THESIS

of Yonsorena Nong (Matriculation No.: 03676276)

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Topic: Evaluation of the Impact of "Erding Ring Closure" on Passenger Flows in Munich Region

The Erding Ring Closure (Erdinger Ringschluss) is a proposed plan for passenger rail transport in Munich region. The regional planning authority of Munich region views this project as a key opportunity to improve the airport access, minimize the travel time, and provide direct commuter rail transport from Freising to Erding via Munich Airport. Upon completion, the newly constructed line of urban rail transit will have a series of influences on the whole city public transportation network. In this context, a study on travel time and passenger flow to Munich airport will be conducted. Since the new transit line will provide a direct connection between Munich airport and Messe, the travel time between these stations will also be assessed. Furthermore, an assessment of passenger flow on Stammstrecke will be made as it will have new characteristic due to the new transit line going into operation.

To investigate the effect of Erding Ring Closure, a passenger flow prediction framework will be built and the prediction model will be constructed. The simulation will be conducted and performed using VISUM. Moreover, the results from the simulations will be analyzed to predict the changes in mode shift and passenger volume of a new line of urban rail transit.

The research conducted in this thesis will help deliver a better insight into the future travel demand in Munich region. Finally, the results from the comparison between the base scenario and the scenarios with the Erding Ring Closure will help us identify its effect.

The student will present intermediate results to the supervisors (Prof. Dr.-Ing. Rolf Möckel and Hema Sharanya Rayaprolu) in the fifth, tenth, 15th and 20th week.

The student must hold a 20-minute presentation with a subsequent discussion at the most two months after the submission of the thesis. The presentation will be considered in the final grade in cases where the thesis itself cannot be clearly evaluated.

Moeckel

Prof. Dr.-Ing. Rolf Moeckel

Student's signature

R. Hema Sharanya

Hema Sharanya Rayaprolu

Abstract

With an increasing awareness of sustainability, most major European cities have invested in public transport to tackle increasing congestion, reduce high reliance on automobile, and reduce daily mobility costs. Studies revealed that making changes to infrastructure or overall quality of service of public transport may have significant impact on daily mobility of individuals and transit ridership. One anticipated project discussed in this thesis is Erding Ring Closure, a new rail connection between Erding and Munich Airport. As the project involves large scale development, feasible study of its impact is deserved.

This thesis aims to investigate the potential effects of the Erding Ring Closure on passenger flows in Munich region. To realize the impact of the project on individual mobility behavior as a consequence of infrastructure and quality service improvement, a discrete mode choice model and a route choice model are built. The study explicitly includes both short and long-distance travel model within a single model framework. While the trip to airport is modeled based on long-distance travel model, the urban travel model is implemented for commuting and other trip. Only two alternatives are considered in the study - auto and transit.

The study determines the influence of new opening service on mode choice using a binary logit model. Constrained by the lack of data available, derived parameters from previous research are adopted to formulate mode choice model. Equilibrium assignment and timetable-based approach are applied to allocate the mode-specific trips on the routes and links. PTV VISUM, a macro traffic flow simulation, is used to facilitate the analysis process of mode choice and route assignment. Three scenarios are modeled to predict the changes in modal split as well as to test the model sensitivity. Those scenarios are scenario with Erding Ring Closure and the other two scenarios with increasing auto operating cost and parking cost after Erding Ring Closure is put into service.

Model results of scenario with Erding Ring Closure provides evidence that additional transit service has not been sufficient to have a substantial impact on modal split in Munich region, although there has been less of a reduction in auto and slower growth in transit in comparison to base scenario. The minimal positive effects of Erding Ring Closure may indicate travel time is still the most important factor that affect individual decision on travel mode. Another two scenarios tell a very different story. The scenario with high operating cost and parking cost shows a growth in transit share regardless of trip purposes. Besides, the study fails to perform and analyze the assignment task as unrealistic results is yield from the model. The study concludes by addressing the impact of Erding Ring Closure on travel mode share.

Acknowledgment

First of all, I would like to express my profound gratitude to my advisor, Hema Sharanya Rayaprolu for her continual advice, support, and her trust in my ability. Her guidance and advice are invaluable and indispensable. Thank you for your patience, encouragement, and immense knowledge you gave me within this 6 months.

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Declaration concerning the Master's Thesis

I hereby confirm that the presented thesis work has been done independently and using only the sources and resources as are listed. This thesis has not previously been submitted elsewhere for purposes of assessment.

Munich, March 7th, 2018

Yonsorena Nong

Contents

List of Figures

List of Tables

List of Abbreviations

ADAC	Allgemeiner Deutscher Automobilclub e.V
AOC	Auto Operating Cost
HA	Home-Airport
HO	Home-Other
HW	Home-Work
MiD	Mobilität in Deutschland
MVG	Münchner Verkehrgesellschaft
MVV	Münchner Verkehr und Tariffverbund
OD	Origin Destination
PrT	Private Transport
PuT	Public Transport
PC	Parking Cost
PKT	Passenger Kilometer Travel
TAZ	Transport Analysis Zone
VDV	Vereband Deutshcer Verkehersunternehmen
VMT	Vehicle Mile Travel

Chapter 1

Introduction

Special attention has been given to public transport because its role in transportation has a huge impact on the quality of life in the society. As considered by many, public transport closes a gap between social and economic mobility, and improves ecological sustainability (Eichmann, Berschin, Bracher, & Winter, 2005). There is a mounting evidence that the rapid development of urban rail transit is taken place due to the current traffic congestion, increasing environmental issues, and the heavy load of private transport on the road.

In Germany, there are many types of mass rapid transit in operation, ranging from bus to subway. Noticeably, one of rapid transit types is suburban rail systems called S-Bahn or Schnellstadtbahn, the hybrid urban-suburban type which operates in almost all major metro areas. S-Bahn serves and connects the urban as well as suburbs to many regional towns. Like other rail transits around the world, S-Bahn system in Germany is well-established and a very well-integrated public transport network. Some of the good model networks can be found in Munich, Berlin, or Rhein-Ruhr.

In the last two decades, intensive upgrade and expansion of the mass transit system in Germany have been undertaken to acknowledge the needs for a better and convenient mobility. One of the major rapid transit project is Erdinger Ring Closure (German: *Erdinger Ringschluss*), a proposed new rail connection between Erding and Munich Airport. This new development has attracted not only the attention of public, but also traffic planners and researchers. The government and project developer believe that the project is a promising development that aims to promote local transport within the regions. Moreover, this development also emphasizes a clear tendency of the regional planning authority in Munich region regarding the improvement of public transport. The development of this project could make the urban rail transit and regional rail transit more attractive. Also, it improves the accessibility of certain destinations in Erding and other regions in the northeast of Munich.

There is evidence that improvement of the infrastructure or the services usually have a large impact on transit ridership. Munich's public transport network is expected to have a new characteristic on both passenger flows and distribution on the entire network when the new S-Bahn service is put into operation. In this case, the new line route will impose a significant impact on the network, such as causing changes in passenger volumes and distribution features on other line routes. It is therefore necessary to investigate the growth patterns of traffic network and assess the influence of new service.

1.1 Background of Erding Ring Closure

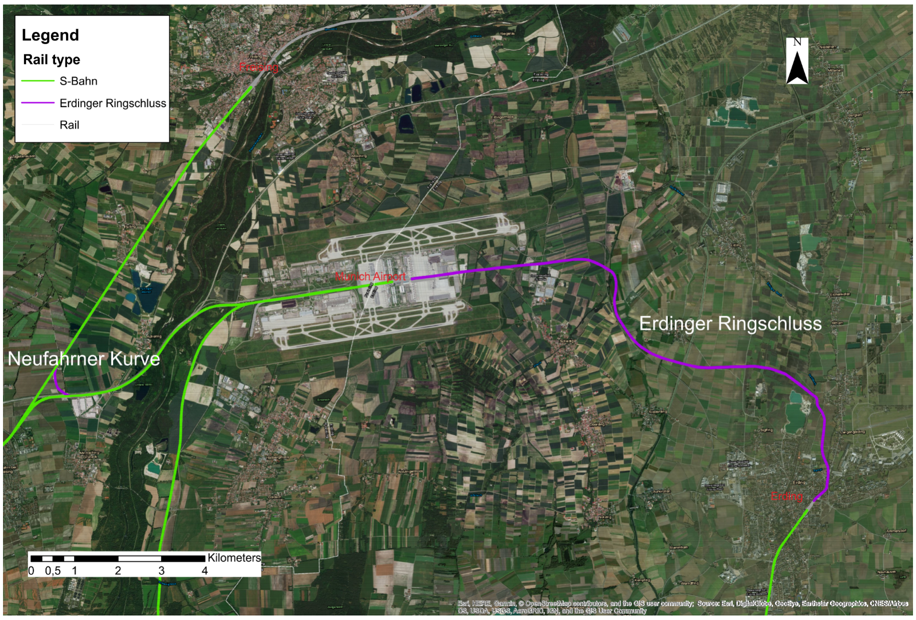

Figure 1.1: Erding Ring Closure
Source: Openstreetmap and elaborated by Author with ArcGIS

The Erding Ring Closure (German: *Erdinger Ringschluss*) is a proposed passenger rail transport project in Erding (see Figure 1.1). It is the second major rail transport development after 2nd Trunk Tunnel (German: *2nd Stammstrecke*) which has been approved by government of Free State of Bavaria. Upon completion, an exclusive S-Bahn service will be operated between Freising and Erding via Munich Airport. In addition to S-Bahn service, two new additional service will also be put into service to serve airport bound trips e.g. trans-regional airport express (German: *Überregionaler Flughafenexpress, ÜFEX*) and airport express (German: *Flug hafenexpress, FEX*) (Bayerishes Staatministerium des Innern, für Bau und Verkehr [STMI], 2010).

For decades, there is an ongoing discussion on a connection between Erding and Munich Airport, which would be an important alternative to the existing transit connections to the airport. At the same time, this connection is also a prerequisite for a better connection to southeastern Bavaria. At present time, there is a missing rail connection between Erding and airport, and therefore a direct connection between Erding and Freising as well. Commuters from Erding to airport or Freising have to use modes other than rail transit (e.g., bus, car-sharing, or private vehicles). Journey with bus would be less convenient and comfort especially for passengers carrying big and a lot of luggage. On the other hand, traveling with personal private vehicles would be much better in most situations, but however with higher mobility cost. Therefore, this development is a key opportunity to improve the airport access, minimize the travel time, and provide direct commuter rail transport from Freising to Erding via Munich Airport. Apart from the airport bound access, the ring closure also plays an important role in relieving the effects on other lines and traffic load in Munich's city center. Under this circumstance, visitors for the fair in Messestadt would no longer have to travel via Hauptbahnhof or Ostbahnhof as the Messestadt of Riem would be directly connected to the airport.

1.2 Objective

The purpose of the thesis is to address the characteristics of passenger flows before and after the new transit service on Erding Ring Closure is introduced. The study is carried out based on the conventional four-steps model by using VISUM, an integrated transport planning software. In this research, a mode choice model is built to help formulating and estimating modal split and subsequently analyzing route assignment in the later stage. The goal of the thesis can be achieved through this research question:

How does the Erding Ring Closure affect the mode choice and route choice of a number of trips in Munich Region?

In this thesis, I have divided the tasks into several steps, which are a critical stepping stone in leading this research toward the goal. The following tasks are carried out to support answering the research question:

1. Predicting the number of trips based on individual mode (Auto and Transit)
2. Building mode choice model for the study
3. Analyzing and formulating the trip assignment procedure
4. Forecasting the mode choice and route choice under the scenario "Erding Ring Closure", scenario doubled auto operating cost, and scenario doubled parking cost

The research conducted in this thesis will deliver a better insight into the future travel demand in Munich region, especially the northeasten part of Munich and Erding. Finally, the results from the comparison between the base scenario and the scenarios with the Erding Ring Closure will help us identify its effect. The results from this study can also be used to support other future researches related to airport demand modeling.

1.3 Outline

The thesis is organized into 8 Chapters as follows:

- Chapter 2 discusses mainly the relevant literature in general for this thesis. The chapter begins with the review of previous studies and further describes the theory and approach of mode choice and route assignment.
- Chapter 3 outlines the methodology used in this thesis and briefly explains its procedures.
- Chapter 4 details the data used to build the model.
- Chapter 5 describes how the study area is selected and discusses the current situation provided with relevant information.
- Chapter 6 explains the modeling framework which includes the discussion of model specification, building, and estimation.
- Chapter 7 focuses on the comparison between based scenario and scenario with Erding Ring Closure according to the model built in chapter 6.
- Chapter 8 summarizes the study with a reflection, and outlines the limitations of the study with a suggestion for future researches.

Chapter 2

Literature Reviews

The chapter of Literature review is structured into two major parts. The first part focuses on the relevant literature (previous researches with similar point of interests). As several studies have already been conducted to analyze impacts of new transit lines in urban areas, the review of these studies will provide me some initial clues on the study results to be expected. The second part of this chapter briefly discusses about the theoretical literature (e.g., four-steps model, mode choice modeling, and route assignment). Also in this part, principal theory of four-steps model and its comprehensive application in the scope of transport system analysis will be discussed. Then it outlines the third and fourth step of the conventional four-steps model by providing the basic theory and its practical application with a concise explanation.

2.1 Impact of new transit infrastructure

Undeniably, adding new transit lines, adding a highway lane, or building a complete new highway will change the network topology. Many studies have been conducted to investigate the correlation between urban mobility and performance of transport supply by analyzing the changes in infrastructure and services. Through empirical analysis, there is evidence that expanding transit infrastructure, improving transit services, and making cities friendly to non-motorized transports (i.e., pedestrian and bike) can directly affect individual mobility behavior.

Li (2015) noted that on grounds of a new transit line, the current passenger flows are like to change because of the new network structures. To a greater extend, Li explained that the expansion of the network will likely pose as an important significance on flow generation and distribution on each line. Likewise, Zheng (2008) also stated that the characteristic of passenger flow will change when the network connectivity is improved. Zheng conducted a study on the impact of new rail transit line on passenger flow in Shanghai and systematically summarized that passenger volume on each line and traveler's mobility choice are influenced by the enhancement of the connectivity of the whole network. For instance, passenger favors the path with shorter travel time and less transfer.

In a paper, Nixon et al., (2015) examined the changes in travel behavior of travelers in Los Angeles before and after the opening of new light rail transit service (LRT). They conducted a travel survey along Exposition and Crenshaw corridor where LRT will be operated along side the bus. Interestingly, they found that the newly introduced LRT has negative effects on overall transit ridership. For instance, bus ridership saw a dramatic reduction mainly due to the service changes. Furthermore, the study indicated that there is significant decrease in driving (vehicle miles travel [VMT]) of households who live within 1 km buffer zone of new LRT station. In contrast, those households living near bus stops removed increased their driving because of new LRT service.

In another study, Li (2015) investigated if the additional of new urban rail transit line in Beijing will influence the passenger flow distribution in the network. The study found that the changes of passenger flow characteristics caused by the opening of different kinds of new subway lines can result in convenient transfer as well as increasing in passenger volume. According to the study, the current network alters significantly when new urban trunk line and supplementary loop line are in service. Opening of urban trunk line will increase the passenger volume of most transfer stations while new loop line (outer ring) will reduce passenger volume on the existing inner ring line. However, the study did not disclose the shift in mode choice between private and public transport. On top of that, Li emphasized that the land-use patterns and sub-urbanization process are directly affected by transport supply improvement. On these terms, it refines the land development intensity and widens passenger perception on rail transit.

Djoko (2014) analyzed the significant impact of proposed new metro line in Stockholm on the public transport network in his study. Even though his study focused only on the public transport (metro and bus), the study found interesting results with respects to travel time saving and passenger load. With the new metro line, travel times from Danderyds sjukhus station to Älvsjö station was notably reduced compared to current situation. Distrubtion of passenger loads on this north-south service also changed. The analysis saw a sharp decrease in occupancy rate on the bus line because the new metro would attract long distance passengers from the bus. Moreover, the new metro line was also able to relieve the congestion at the most crowded station in the network.

Besides, Siemen AG (2012) studied the impact of new public transport mode, LRT in Turku. The study was conducted to assess any beneficial impacts of LRT on society, ecology, and environment. The study compared the base scenario with the scenario with LRT that will be implemented in 2025 and 2035. Interestingly, the study found that the addition of LRT will decrease the car share in the modal split. The study further pointed out that LRT will partially replace the bus and attract car users. Moreover, passenger kilometers travel (PKT) with public transport also experiences positive increase with the implementation of LRT.

2.1.1 Remark

Results from above papers may not be as homogeneous as it seems. This might be due to the pattern of transport network, location of study area, different travel behavior, and other associated factors. Some studies found that the shift from one alternative to another alternative has been wide as expected while some suggested that the new transit line did not add any competition to another modes. However, those studies have provided evidence that the change in network pattern can result in inducing more demand. In particular, better accessibility to a certain destination means more people will travel to perform the activity there.

2.2 Four-Steps Model

Four-steps travel demand models are a traditional travel demand modeling procedure, primarily used to forecast the future demand and performance of a transport system. Four-steps model (FSM) is a simplified representation of reality which is suitable for large scale infrastructure project and not appropriate for subtle and complex policies that involve the analysis of individual travel behavior. FSM is a trip based model that perform the analysis based on the number of trips and estimate travel with different means of transport at the aggregate zonal level (McNally, 2007).

Normally, calculation for entire model of FSM involves four steps in sequence, and each step serves different purposes that would subsequently build up a model called four steps model. As defined by various traffic analysts and expertise, the four steps of the classical four-step models are:

- **Trip Generation**: determines the number of trips attracted and produced in each zone by trip purpose, as a function of land uses and household demographics, and other socioeconomic factors.
- **Trip Distribution**: matches the attraction and production trips between all zones of each trip purpose. The estimation is often measured with travel impedance (time and/or cost).
- **Mode Choice**: factors the trips and computes the proportion of trips for each particular mode of transport.
- **Route Assignment**: trips between origin and destination are distributed to mode specific network. Several factors such as minimum travel time and/or congestion are considered to determine the traffic volumes.

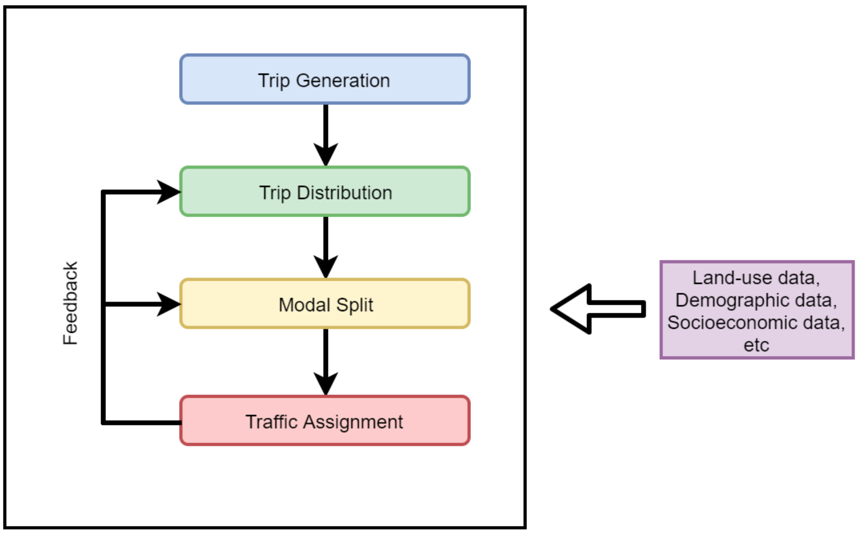

Figure 2.1: Standard Four-steps models
Source: Adapted from EPA420-R-97-007, 1997

2.3 Mode Choice

To clarify the question of what impact the infrastructure measures have on the mode choice, the definition of mode choice must first be defined. Modal split is the distribution of transport demand among the different modes of transport (Kirchhoff, 2002). It arises from the fact that people decide for their paths to be traveled with a particular mode of transport. In transport planning, mode choice is one of four sequential planning stage. The third step of four-steps model effectively factors the trip matrices from trip distribution to allocate the incurred trips on the existing modes. This analysis allows modeler to determine the proportion of existing modes on network and reflect the choice probabilities of individual trip makers.

2.3.1 Factors influencing the choice of mode

The traveler's preference on alternative choice set is notably influenced by many various factors, ranging from transport-specific factors (describing the various parts of the transport system) to individual-related factors, namely car ownership or income (Olsson, 2003). Ortúzar and Willumsen (2011) classified these factors as follows:

- Characteristics of individual: relates to not only personal attributes of trip maker, but also to a certain degree of household, for example, car availability, possession of driving license, size of household.
- Characteristics of journey: relates to the trip itself, for example, trip purpose, time of the day.
- Characteristics of transport facilities: relates to the various components of transport system, for example, timetables, relative travel time, monetary travel cost, parking cost.

2.3.2 Discrete Choice Theory

Earlier development of mode choice model was more concerned with the usual analytic approach, aggregate travel demand. Traffic planners often used aggregate approach to demonstrate the travel demand forecasting process. Travel data are often subdivided into zones, called travel analysis zones (TAZs) prior to the determination of travel patterns (including intensity of land-use and socioeconomic of population) (Weiner, 1997, p. 42). However, the focus on econometric and psychometric modeling has led to a major development of disaggregate travel demand models. Currently, the development of mode choice model is more concerned with the disaggregate level which is based on the discrete choice analysis methods. In contrast to the aggregate approach, Koppelman and Bhat (2006) stated that the disaggregate model is used more often because it can reflect an individual's choice on one alternative among a finite set of alternatives. To some extend, the model is built based on the individual attribute related to trip makers rather than statistical associations of a larger group (Ji, 2017).

The discrete choice model is an empirical model derived from utility theory. The model uses the principle of utility maximization to explore the choice of individual. The widely adopted function of utility maximization gives us an initial clue that an individual chooses the alternative that has the highest utility among a choice set (Schiffer, 2012, p. 32). This also means that individuals with the same attribute values and similar socio-economic characteristics would always select the same alternative. However, this is unrealistic because similar individuals can still choose different alternatives. To address these irrationalities, some random components are added to the utility function, and thus makes utility model random as well. Utility function can then be formulated through a combination of systematic components V_{in} and random components (disturbances) ε_{in}.

The equation is as follows:

$$U_{in} = V_{in} + \varepsilon_{in} \tag{2.1}$$

(Equation source: Ben-Akiva and Lerman, 1985, p. 60)

where:

U_{in} : utility of an alternative i to the decision maker n

V_{in} : systematic components of utility i

ε_{in} : random variable of error portion of the utility

The observable portion of the utility V_i is a function and assumed to be deterministic which is expressed by the following equation:

$$V_{in} = \beta_1 x_{in1} + \beta_2 x_{in2} + \beta_3 x_{in3} + ... + \beta_K x_{inK} \tag{2.2}$$

(Equation source: Ben-Akiva and Lerman, 1985, p. 63)

where:

x_{in1},x_{in2},x_{in3},...,x_{inK} : the independent variables that include both attributes of the alternative i and socioeconomic variables of the individual n

β_1,β_2,β_3,...,β_K : the unknown parameters

Parameters β for each attribute can be asserted with Maximum Likelihood Estimation (MLE). The random component ε is basically represented by a probability distribution. However, it is important to note that different assumptions about the distribution of ε can result in different type of discrete choice models (Ben-Akiva & Lerman, 1985, p. 65).

Considering the choice set containing only two alternatives i and j, the following models are applicable for the binary case. The models described in the following sections depict discrete decisions, that is, behavioral choice with a finite number of distinguishable options. A related point to consider is that some of the decisions are due to the economic theory of utility maximization, as well as that some of the random decisions, or not to be fully replicated. The models presented differ in the way that they assume different distributions for the random error component. The simplest way is to assume that all random parts of a model follow the same distribution and are independent of each other. This property is called i.i.d (independent and identically distributed) (Lohse & Schneider, 1997).

2.3.3 Linear Probability Model

The Linear Probability Model (LP model) is perhaps the simplest model compared to other models. The model is rooted in the assumption that the difference in disturbances, ε_{jn} - ε_{in} is uniformly distributed between two fixed values -L and L, with L>0. In LP model, the difference of ε_{jn} - ε_{in} and its density function are defined as ε_n and $f(\varepsilon_n)$ respectively. The probability of choice in LP model can be solved according to the following equation:

$$P_n(i) = Pr(\varepsilon_n \leq V_{in} - V_{jn}) \tag{2.3}$$

(Equation source: Ben-Akiva and Lerman, 1985, p. 67)

According to Ben-Akiva and Lerman (1985), the probability of choice for alternative i is given by the cumulative distribution function ε_n. When V is linear in its parameters, the probability function is also linear in the interval -L and L.

Despite being simple to use, this model has a major drawback. Ben-Akiva and Lerman (1985) described the results from the forecasts of LP model as unrealistic due to its "kinks" at the point L and -L. They further emphasized that the model fail to exclude some people who choose alternative i which is predicted by the model with a probability of 0. Another drawback of the model is the specific assumption on interval between -L and L, and zero probabilities outside this interval, and thus makes the model unrealistic (Cox, 1970). Although the calculation is relatively straightforward here, the model is rarely practiced due to its limited application for modeling with a larger set of alternatives, its problematic theoretical foundations, and the existence of better models in transport planning (Schnabel & Lohse, 2011).

2.3.4 Probit Model

In probit model, it is assumed that the random components in utility function can be approached by the sum of a large number of unobserved, but independent components. An important aspect discussed here is the assumption about the distribution of ε_{in} and ε_{jn}. In the form of central limit theorem, the disturbances are normally distributed. Under the assumption of normal distribution for random component, the probability of choice for alternative i is given by:

$$P_n(i) = \Phi\left(\frac{V_{in} - V_{jn}}{\sigma}\right) \tag{2.4}$$

(Equation source: Ben-Akiva and Lerman, 1985, p. 69)

where:

Φ : the standardized cumulative normal distribution

σ : the scale of utility function, usually σ=1

In this model, the probability of choice only depends on σ, and even if the choice for σ is arbitrary, rescaling the σ and β by any positive constant would not affect the choice probability (Ben-Akiva & Lerman, 1985, p. 69).

The distribution function has a sigmoidal shape, in which the probability of choice is never zero or one. It approaches one when V is close to $+\infty$ and zero when V is close to -∞. The normal distribution with these properties is the most realistic representation of the stochastic utilities. However, this model is no longer practicable with more than two alternatives since the model cannot be calculated analytically. Thus, it is not very common in traffic planning (Schnabel & Lohse, 2011). In addition, the model is not considered convenient analytically due to its property of not having closed form (Ben-Akiva & Lerman, 1985, p. 70).

2.3.5 Logit Model

Logit and probit models are very much alike, but what makes logit different from probit is the integral for the choice probability has a closed form. In terms of this property, logit model is considered analytically more convenient. Logit model relies on the assumption that the difference in disturbances ε_n is logistically distributed (Ben-Akiva & Lerman, 1985, p. 71). By virtue of this assumption, it means that all individual error component ε_{in} and ε_{jn} is distributed independently and type I extreme value (identically Gumbel distributed).

Assuming Gumbel Distribution for ε_n, the probability that individual choosing alternative i is expressed according to binary case as follows:

$$P_n(i) = \frac{e^{\mu\ V_{in}}}{e^{\mu\ V_{in}} + e^{\mu\ V_{jn}}} \tag{2.5}$$

(Equation source: Ben-Akiva and Lerman, 1985, p. 71)

where:

μ : the positive scale parameter

For convenience, Ben-Akiva and Lerman (1985) suggested that μ should be assumed to be one, similarly to the σ=1 in probit model. However, it is worth noting that the standard scaling parameter for binary probit corresponds to the $var(\varepsilon_{jn}$ - $\varepsilon_{in})$=1.

Even though logit model is widely used in comparison to other models, this model is incapable of capturing the correlation between alternatives. Ortúzar and Willumsen (2011) emphasized that logit model has the important IIA property (Independence from Irrelevant Alternatives property), which implies that the choice probabilities of two alternatives are not influenced by the existence of other alternatives. In reality, however, alternatives are not completely independent. A well-known example for it is red-bus and blue-bus.

2.3.6 Other Models

Other common types of mode choice models is multinomial logit model (MNL), which is to some extend an extension of binary logit model. MNL is commonly used in the case when more than two alternatives are available in the network. Apart from MNL, the nested logit model (NL) is developed to deal with the major limitation of MNL Model. Basically, the NL model is an extension application of the MNL model whose decision is made in sequential process (Forinash & Koppelman, 1993, p. 99). As with the name itself, NL divides the choice alternatives into so-called nests. The model is rooted with the assumption that the random error terms are shared among the alternatives (Koppelman & Bhat, 2009, p. 159). The alternatives that are grouped in a nest are independent of each other. Hence, the IIA property is also within the nests. Between the nests, the probabilities of chosen alternative may depend on the existence or characteristics of other alternatives. The nested logit model assumes Gumbel distribution for the error terms, ε for each alternative whose the value lies between 0 and 1. Moreover, the model further assumes that the independent portion of the random variables for the nested alternatives are still independently distributed, but with a scale factor between 0 and θ (Forinash & Koppelman, 1993; Koppelman & Bhat, 2009).

2.4 Airport choice model

Due to the scope of study that explicitly includes the airport trip within a single model framework, the review of airport choice model is favored in this thesis. Airport choice model is often modeled based on long distance travel model. The reason for it is because majority of travelers to airport are long-distance traveler and they tend to stay longer at their destination than short-distance travelers. Airport trips tend to be done by auto or transit. On the other hand, travel mode like bike is not taken into account though it is possible that airport employee will bike to work. As cited in Moeckel et al. (2015), the following long-distance mode choice models offers the discussion of airport choice.

Blackstone et al. (2006) conducted a survey for airport choice from Baltimore to New York, that includes the major airports BWI, EWR, JFK, and PHI. Through their empirical analysis, the results presented in the study indicated that location of the workplace has a crucial impact on the decision process. For instance, business travelers with air decides on which airport to be used based on their workplace.

In another study, Başar and Bhat (2004) analyzed airport choice through their developed probabilistic choice set multinomial logit model. The study was set in the San Francisco Bay Area, where three major airports SFO, SJC, and OAK serve. The study found that frequency of service is also an important explanatory variable in addition to the access time.

Besides Blackstone et al. (2006) and Başar and Bhat (2004), Hess et al. (2007) analyzed the results from stated preference survey. The model built was estimated from the attribute that can be directly observed such as air fare, access time, or number of transfer. The analysis highlighted the significant effect of ground-level distance on airport-choice behaviour.

Other similar studies on airport choice can be referenced to the previous studies by Pel and Nijkamp (2001), Pel and Nijkamp (2003), Hess and Polak (2005), and Hess and Polak (2006a,b). Those studies adopted more sophisticated choice models such as nested logit model, cross-nested logit model, and mixed multinomial logit model.

In contrast to most other studies, Moeckel et al. (2015) developed a nested R^3 logit model for long distance travel model in North Carolina. Unlike other studies that focus on airport choice, Moeckel et al. adopted station choice in their study for non-air modes (i.e., bus and rail). This approach seems to be more rational because the each major areas in North Carolina has only one major airport.

Despite the increasing importance of long-distance travel in transport modeling, only a few studies on long-distance travel model exist. It is also important to note that study on long-distance travel model usually face with lack of data. The challenge is that long distance travel is a rare cases part of daily mobility and thus experiences a very limited data availability (Frei, 2008; Moeckel et al., 2015).

2.4.1 Heuristically derived parameters

Unknown parameters $\beta_1 ... \beta_k$ of observable variables are often econometrically estimated from a sample of observation. Given the data-rich environment, parameters estimation can be done with ease; however, in the case of very limited data availability, parameter estimation would be a great challenging task. This is to say, insufficient data can yield weak coefficients (Moeckel et al., 2015), and that is considered implausible as well. Therefore, in light of theses stressors, some scholars have turned to the application of heuristically derived parameters (Moeckel et al., 2010; Alliance Transportation Group, 2015). The value in deriving a model is obtainable through a number of methods (i.e., previous mode choice modeling experience, literature review, adjustment of parameter, and sensitivity analysis) (Moeckel et al., 2015). One favored study with derived parameters for this thesis can be referenced to a previous long distance mode choice study conducted by Moeckel et al. (2015). The decision for it could be explained by the transferbility of the coefficients derived in that paper.

Moeckel et al. (2015) conducted a study on long distance travel model in North Carolina. The study used the derived parameters to formulate mode choice model rather than estimating model parameters. They derived the parameters based on their accumulated experiences and through literature review. A couple of tasks were exercised, including comparing parameters with other models and conducting series of sensitivity tests to ensure the reasonability of parameters selected. Finally, adjustment of the parameters was carried out to explore the impact of single parameters. The derived parameter results are found to be rational within the range of other models reviewed in the paper.

2.4.2 Remark

The models reviewed in Section 2.4 were originally described and discussed in the study by Moeckel, Fussell, and Donnelly (2015). This thesis only re-discusses the models based on the original works.

2.5 Route Assignment

The last step of four-steps model describes the allocation of the traffic flows on the transport infrastructure. This step fundamentally calculates the routing of the road users, and consequently the load on the routes and nodes on the basis of an integrated network model.

It is to be noted that there are three important information required for solving and formulating a traffic assignment model. First information is travel demand which is systematically done in the three earlier stages of the conventional four-steps model. Second required component is the characteristics of transport supply. The model needs to determine the correlation between travel demand and the transport system. The last information is a method of evaluating the corresponding distribution of the travel demand over the transport system (IHT, 1997, p. 91; Chow, 2007). All-or-Nothing, Wardrop's equilibrium, incremental, or capacity-restraint assignment are the most common approaches used for the route assignment as details in the following sections.

2.5.1 All-or-Nothing

All-or-Nothing (AON) is the simplest model vis-à-vis other assignment methods. AON is based on the assumption that the road networks are free of congestion and the volume of traffic does not affect the travel time and cost. That is to say that travel time and cost are fixed inputs and independent from congestion effects. This model exhibits unrealistic situation as all the drivers perceive the same travel time and cost and subsequently choose the same route even there is another path with nearly the same travel time or cost (Mathew & Rao, 2007, p. 2). However, this model may be deemed reasonable in the case of sparse and uncongested networks where few alternative routes and a large variation in travel cost present. Virtually, the most important application of AON in practice is being a building block for other assignment methods.

2.5.2 Capacity-restraint Assignment

Capacity-restraint assignment aims to approximate an equilibrium solution by involving a sequential application of iterated All-or-Nothing assignment. The function then uses congest function to recalculates the link travel times in relation to link capacity (Victor & Ponnuswamy, 2012). Conventionally, route choice has been calculated on the basis of ideal travel times in an empty network. The link travel time used in assignment is a function of speed on that link. That is to say that travel times will increase in a congested network when speeds decrease. The CR-Function is modeled as follows:

$$t = t_0(1 + a\left(\frac{V}{C}\right)^b) \tag{2.6}$$

(Equation source: US Bureau of Public Roads, 1964)

where:

t : congested travel time

t_0 : travel time (free flow)

V : traffic volume on link

C : capacity of link

a and b : parameters

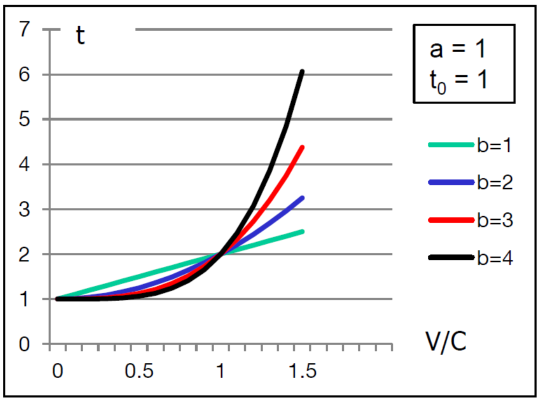

Figure 2.2: Graph of CR-Function with different parameter of b
Source: US Bureau of Public Roads, 1964

2.5.3 Incremental Assignment

Incremental assignment is mathematical process in which traffic volumes are incrementally separated into a number of layers that are successively assigned to the best paths with the All-or-Nothing method. Traditionally, three iteration steps are allocated with a fixed proportion of travel demand (e.g. 50%, 30%, and 20%). Travel times on the link are then determined according to the traffic volumes on the link in each iteration step. When there are many increments used in this method, a set of possible errors in evaluation process may occur because of the discrepancies between travel times and traffic volumes on link. Also, incremental assignment often produces additional systematic biased results due to the influence of the assignment's order of OD pairs' volumes (Mathew & Rao, 2007, p. 6).

2.5.4 Wardrop's First Principle - User Equilibriums

User equilibrium refers to as Wardrop's first principle or Wardrop's equilibrium. The principle is based on the assumption that every road user tries to minimize his or her individual travel time (or, more generally, to maximize its benefits). The resulting state of equilibrium denotes that no road user can further reduce his/her effort. Wardrop's first principle describes the user equilibrium in choosing the route alternatives r for each element $F_{ijk}(\mathrm{t}) = F_m$ of the trip matrix. The formula is expressed as follow:

$$T_r^m = \begin{cases} T_{min}^m & \text{if } F_{m,r} = F_m w_r \\ > T_{min}^m & \text{if } F_{m,r} = w_r = 0 \end{cases} \tag{2.7}$$

(Equation source: Treiber, 2017)

where:

T_r : travel time (generally: negative utility) of route alternatives r

T_{min} : minimum travel time

w_r : the proportion of the travel matrix element which has been allocated to the route r

Wadrop's first principle remains questionable as some analysts have probed whether the Wardrop's user equilibrium in practice (at least in a good approximation) is attainable. The assumption of individual benefit optimization is very plausible. However, the assumption of complete information and an objective definition of the benefit for all road users seems questionable (Treiber, 2017).

2.5.5 Wardrop's First Principle - Stochastic User Equilibrium

User equilibrium assignment is a deterministic equilibrium which roots in an assumption that travel costs on used routes are equal and less than those on unused routes. Also, Wardrop stated that such model assumes the road users to have a perfect knowledge about the traffic condition (Gupta, 2010). Unlike user equilibrium, stochastic user equilibrium allows minimum (perceived) travel cost to be modeled for traffic assignment. The underlying assumption is road users perceive the travel cost on any given route differently and that the routes with the most minimum (cheapest) travel cost attract most trips between each OD pair (Mathew & Rao, 2007, p. 6). The models have distinct advantage over other models owing to their stability and independence of flows and they are less sensitive in response to slight changes in network definitions or link costs. The good aspect of the model is that they take multiple routes into account at one trip assignment and assign the trips on account of their good characteristics (Gupta, 2010). The models are practically most suitable for use in uncongested traffic conditions (Mathew & Rao, 2007, p. 6).

2.6 Traffic Simulation Application

Transport modeling software plays a critical role when analyzing the travel demand. To facilitate the study, traffic analysts often use computer-based traffic simulation that can model the entire traffic network as realistically as possible. These software has been a realistic and useful tool for researchers and expert to realize the effects of any transport related projects in advance and to optimize individual components. Moreover, many different scenarios can be simulated and evaluated in a short period of time and with relatively little personnel and financial outlay.

2.6.1 Overview of VISUM 17

VISUM is macroscopic traffic simulation software developed by PTV AG in Karlsruhe, Germany. The software is often used by many traffic analyst around the world for prediction of the changes in traffic network at aggregated zonal level. Four-steps model, the conventional macroscopic traffic model, is also available in the software.

Traffic engineers and transport planners use VISUM not only for transport planning, but also use it as a powerful analysis and data management tool. What is good in VISUM is its ability to detail the sophisticated routes and schedules of public transport service with a data model that goes far beyond traditional demand models (PTV VISUM Manual, 2017). Apart from the software functionality, the transport network in VISUM consists of links, nodes, transit routes, stops and so-called centroid connectors, which link all the zones with the transport network. Characteristics of vehicles such as size, type and weight are not considered in VISUM. Average speed, flow and density are rather used to dictate traffic condition. This is of particular importance in relation to macro simulation.

2.6.2 Mode Choice in VISUM

VISUM offers variety of approaches for mode choice analysis. With the traditional four-steps model, traffic planners can use either Logit, Probit, Kirchoff, or Boxcox to determine the utility function for choice sets. As for logit model, the program is able to apply either binary logit or multinomial logit to determine the probability with parameters estimated from empirical data. The same approach also applies to probit model, either with binary or multinomial choice. Logit model is chosen for this study because it is deemed suitable due to its simplified approach with easy estimation and interpretation, and it is applicable for transit strategies (NCHRP Report 365, 1998; Koppelman & Bhat, 2006). To facilitate the analysis, measurable unit or impedance of each alternative are required to determine what mode will be used. The input of impedance is generally expressed in the form of travel distance, and relative travel time. VISUM calculates this mode-specific impedance between all zones and later summarizes into matrix table called skim matrix. As for private transport, VISUM also allows users to model cost-specific attributes (e.g., travel cost, toll fee) for the study. On public transport side, timetable approach can be used to calculate the impedance for the public transport. With timetable approach, the program is able to compute all required variables for the in-vehicle-time and out-of-vehicle time (e.g., walking time, waiting time, and transfer time).

2.6.3 Route Assignment in VISUM

Private Transport Assignment

VISUM offers users a wide range of assignment methods for private transport assignment procedure. One of the assignment procedures chosen for the study is user equilibrium called the equilibrium assignment in VISUM. As previously mentioned in Chapter 2, Section 2.5.4, the assignment is popularly used by many modelers. The assignment used Wardrop's first principle to distribute the demand. Based on a incremental assignment as an initial solution, the equilibrium state is calculated in a multistage iteration. This assignment method divides demand proportionally over the number of iteration steps defined by a user (Piatkowski & Maciejewski, 2013). The system then begins by checking if the routes with lower impedance can be found in the network. This raises a question on why the system has to check the alternatives with low impedance. Basic principle is vehicles will be loaded on the route with lower impedance; however, they will be shifted to a new route if another new alternative with lower impedance is found for a given connection. The load is distributed to the corresponding routes until all routes have the same impedance. The balance of the load is performed in pairs. That means the route with the lowest impedance receives a higher load than the route with the highest impedance. If no new routes are found, the iteration stops and the user balance is reached (Wermuth, Sommer, & Wulff, 2006).

Public Transport Assignment

As for public transport assignment, VISUM offers three possible search methods (i.e., timetable, headway, and transport system-based) for the analysis. The transport system-based, the simplest PuT assignment method, considers only the associated travel time of the network, and does not distinguish between individual PuT lines (PTV VISUM Manual, 2017). For the head-way based, each line route is described and run times between line stops and headway are taken into account. However, this procedure does not consider the timetable coordination. In this thesis, timetable-based is chosen for the study as it yields better results compared to other two methods. Timetable-based works on the assumption that passengers are aware of the available PuT timetable and use it to find the shortest path between designated OD pairs. Timetable-based involves the precise departure and arrival time of all services of public transport network as a guidance in the path search procedure (PTV VISUM Manual, 2017). In addition to the timetable, this method also considers the coordination of the timetable to help ensure precise results.

Chapter 3

Methodology

The framework of the proposed methodology in the study is presented in Figure 3.1 below. The methodology is structured into three main components: Data Collection, Data Analysis and Processing, and Model Building in VISUM.

To help facilitate the study and reach the objective of the research, a few set of data are required, such as commuting data in Munich Region, passenger survey to the Munich Airport, transit schedule, and geospatial data. Departure-arrival data and commuting data in Munich Metropolitan Region (MMR) are provided by the Assistant Professorship of Modeling Spatial Mobility (MSM). Passenger survey data to Munich Airport is provided by Flughafen München GmbH (FMG). Apart from travel data, geospatial data required for VISUM can be downloaded from Openstreetmap, a platform for freely-reusable geospatial data.

The next step would then be the analysis of the collected data. After the exploratory analysis stage, OD matrices are then generated based on the commuting data and passenger survey to airport. For transit schedule, General Transit Feed Specification (GTFS) is chosen due to its simplicity and its open-source feature. GTFS is created by using the departure-arrival data. Before the model in VISUM is built, the data should be aggregated by the influence zones which is delineated as a spatial unit. Irrelevant data to study area, such as data outside study area, are discarded. Model for the study is then created by using the filtered data. Model diagnostics is carried out to improve the built model. Finally, the model can be used to assess and forecast the travel demand.

Figure 3.2 presents the proposed four-steps model in this thesis. As previously mentioned above, OD matrices are generated based on commuting data in MMR. By adopting the OD matrices, the study saves the analyst time to construct a OD from scratch (through trip generation and distribution stage). This project focuses only on home-based trip, thus three activity pairs are created for the study, namely trip to work, trip to others, and trip to airport. The demand strata are therefore generated according to the activity pairs and person groups (HW, HO, and HA). Demand strata for the return trip (WH, OH, and AH) are not included in the study. A brief explanation on this matter is given in Chapter 4: Dataset. In mode choice stage, trips of each demand stratum are then separated for two particular transport modes, private and public transport. Finally, trips are assigned along the road network in the last step (Route Assignment). Once the base model is firmly built, the analysis is then proceed to the comparison between base scenario and the scenario with Erding Ring Closure.

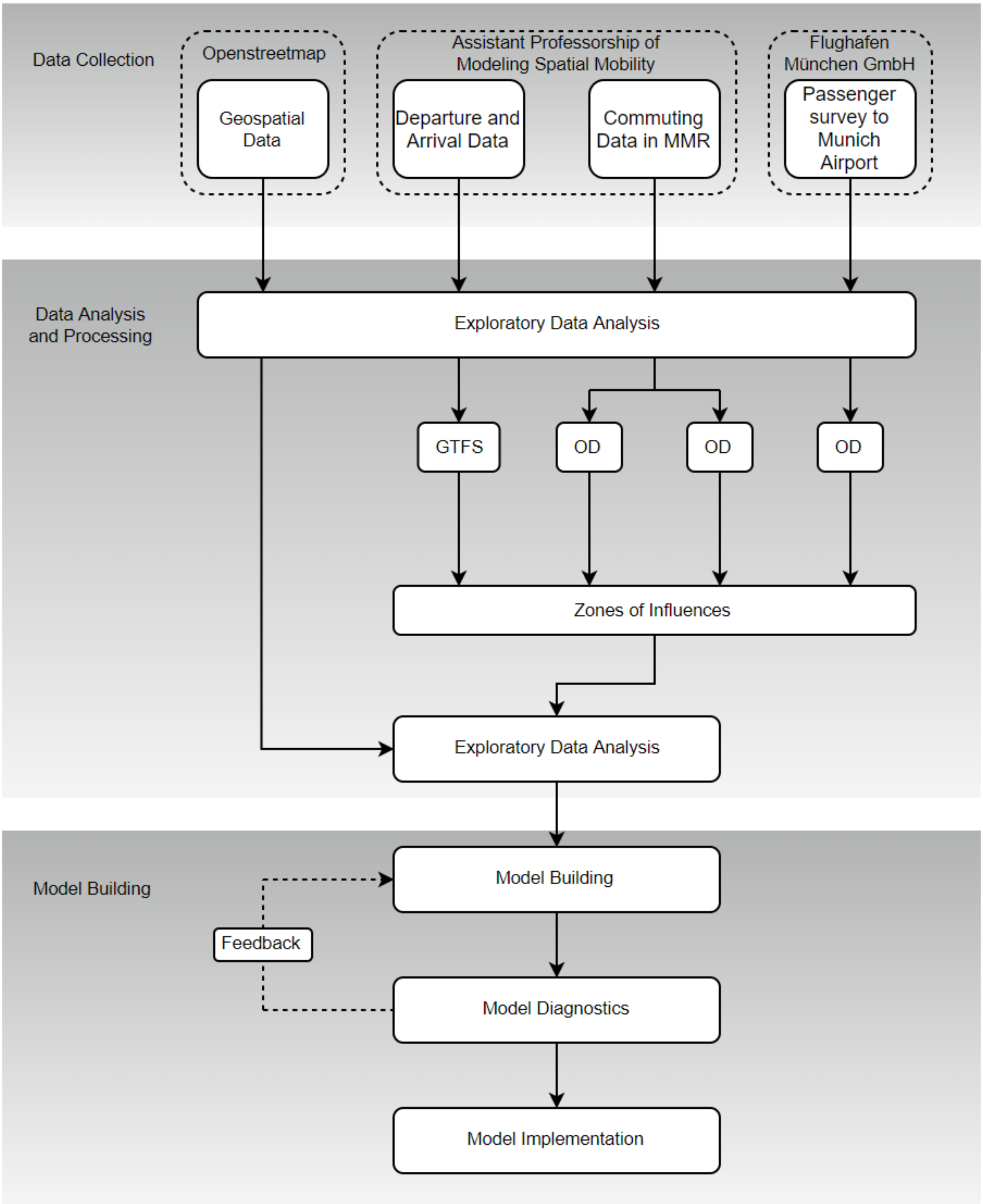

Figure 3.1: Proposed Methodology Framework

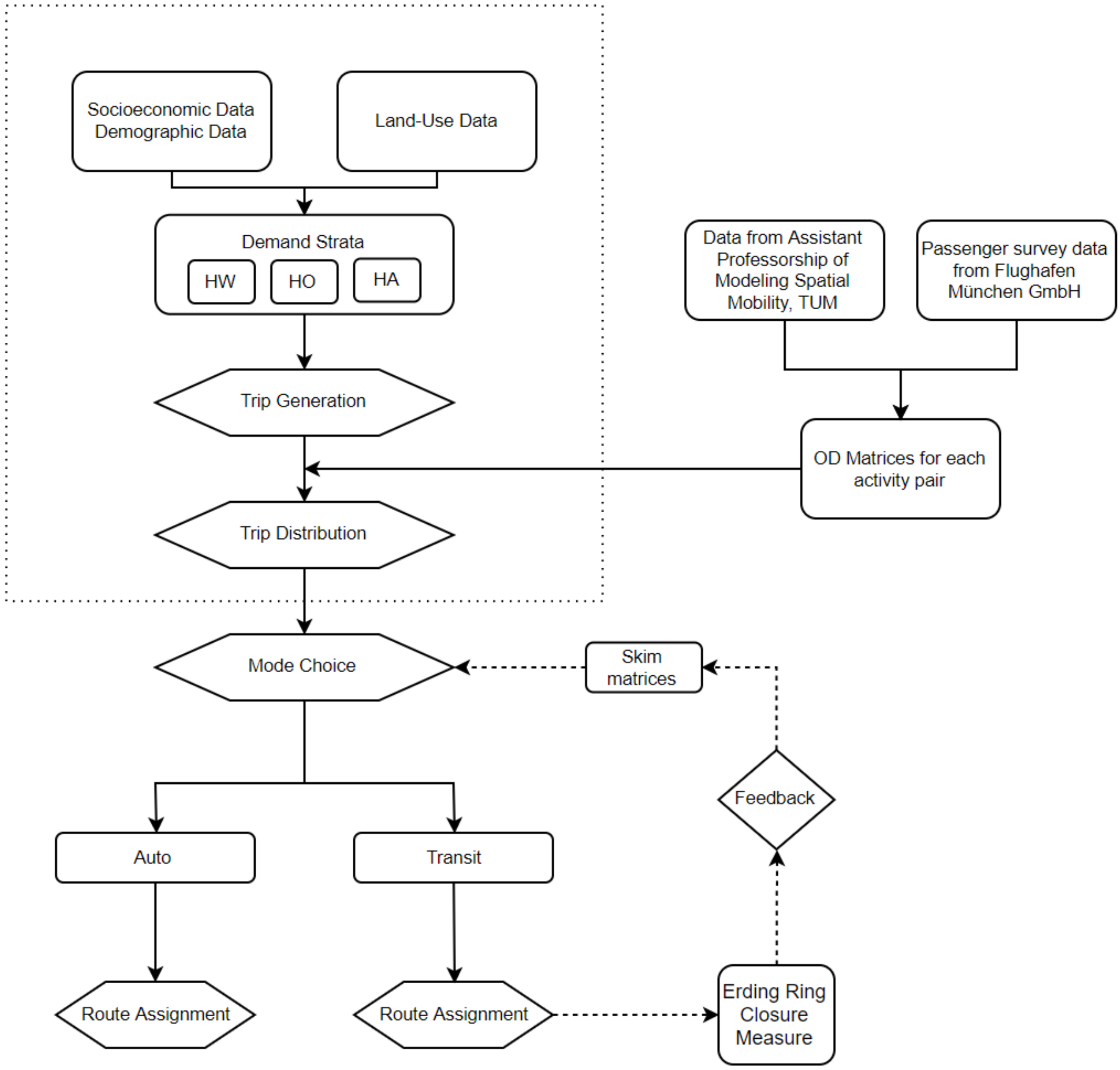

Figure 3.2: Proposed Four-steps model for the study

Chapter 4

Data Analysis and Processing

This chapter explores the method to assess and process the dataset for the study. The first section begins with the method to generate OD matrices from the dataset. Then it outlines the incorporation of exogenous data into the OD matrices. Furthermore, it discusses the assessment of OD matrix. Finally, it briefly explains how GTFS is created and the geospatial data is cleaned through OSMOSIS.

4.1 Generating OD Matrices

The current work relies on two main dataset to formulate the OD matrices for the study. First dataset was provided by the Assistant Professorship of Modeling Spatial Mobility (2017) and retrieved in the form of a CSV file. The dataset are already categorized for four modes (i.e., auto, transit, cycle, and walk). Each dataset contains the Origin and Destination Points for all trips recorded. There are only four trip purposes, namely home-based work, home-based other, and the other two return trips.

As a first step, data with bike and walking were discarded as they were not considered in the study. Then, data with auto and transit were separated by trip purpose which resulted in 8 dataset, 2 for home-based work, 2 for home-based other, 2 for work-home, and 2 for other-home of auto and transit respectively. Secondly, each dataset was then geographically filtered out by the zone of influence which is delineated as spatial unit. Since the model is being built for Munich region, the only trips that were considered were those originate and terminate within Munich region (see Chapter 5 for study area). Trips outside the study area were later removed. This resulted in 2,796 OD pairs for each trip purpose. Table 4.1 summarizes the number of trip by purpose.

Table 4.1: Summary of trips by purpose

Mode	Activity Pair	Description	Total
Auto	HO	Home-based other	618,285
	HW	Home-based work	365,457
	OH	Other-home	618,285
	OW	Work-home	365,457
Transit	HO	Home-based other	238,370
	HW	Home-based work	138,134
	OH	Other-home	238,370
	OW	Work-home	138,134

The number of OH and WH trips shown in the Table 4.1 are found to be equal to HO and HW. This can be logically explained by the assumption that return trip should be equal to outbound trip. According to the dataset, trips with travel distance more than 80 km were discarded. Trips recorded in the dataset are based on trip distance, and thus does not fit to represent mode share. It is worth noting that the dataset contain only the Home-based trip, not the Non-Home-based trip. This is because the data for Non-Home-based trip are not available.

Second dataset used to generate OD matrix for airport is based on passenger survey data provided by Flughafen München GmbH (FMG). Dataset, which is surveyed in 2016, describes the person trip between two modes (i.e., auto and transit). Trips were directly tabled into matrix by assuming one destination for all. For example, each trip is terminated at airport destination. Trip to airport were classified as homebased-airport (HA). Commuting trip to airport is not included in this dataset as it was already covered in HW trip.

4.1.1 Incorporating exogenous data

Commuting data in MMR contains all the information of each trip with certain origin and destination. OD matrices generated from it can be applied and used directly as a distribution model. However, the data is limited only to home-based work trip and home-based other trip. A shortcoming of the data is the lack of commuting data to Munich Airport. Two major tasks were involved to incorporate the passenger data into the study. First task focused on the distribution of trips to its originating zones whereas second task attempted to allocate the trips to its destination zone.

The trip origins recorded in the survey were coded to the system of districts used by FMG. However, at this level of geographical resolution, the resulting data is not considered convenient to represent the trips in each TAZ for airport bound trip. For the purpose of model estimation, the surveyed annual passenger trips to airport was aggregated to a system of TAZs instead of districts resolution. Since the given data was recorded in annual number, an assumption was made to create trip person end (trip per day). It was assumed that annual trips were made in a common calendar year of 365 days. The total number of trip to airport was the sum of total trips per day from each district. Therefore, trip origins from each district were divided by 365 days. Then, the trips were distributed to each TAZ by scaling with the proportion of population in each TAZ.

After trips were distributed to its originating zones, trips were then allocated to four zones that located adjacent with the airport area. Distribution of trips at destination zones were undertaken following the proportion of commuting trip - HW. Airport lies across four zones, and the zone with highest incoming HW trip will receive higher number of airport trips as well. Moreover, special condition was set if all four zones have zero incoming HW trip, airport trip is allocated to zone number 245. The reason for it is most companies' offices locate in zone number 245.

4.1.2 Assessing OD Matrices

Each trip has principally two ends, trips originating in a zone (production end), and trips are destined for a zone (attraction end). Theoretically, the total number of trips produced per zone should be equal to the total number of trips attracted per zone. In practice, however, the estimation of these two trip-ends will not be equal. Under this assumption, balancing method is usually applied at the end of trip generation stage in order to make production equal to attraction trips or vice versa. In particular, the selection of which trip-end to be balanced is done based on the degree of confidence. Trip production has normally greater degree of confidence since it is based on household travel survey, whereas the attractions are based on characteristic of data (location of study area and some external information) (Skarphedinsson, 2009, p. 22). Balancing the producing and attracting trips for each trip purpose is done individually. Between production and attraction trips, if one of them is used to control the total, the other is no longer relevant for the study.

Selection of which trip to be modeled can be referenced back to the balancing approach reviewed above. HW, HO, and HA will be used to to formulate and analyze mode and route choice in VISUM. The return trips WH, OH, Airport-Home (AH) will not be used. By virtue of balancing method, the model can distribute trips done in the direction towards the attractions with higher degree of confidence than towards the productions.

4.2 General Transit Feed Specification (GTFS)

Initially, I considered using public transport timetable from Münchner Verkehrs- und Tarifverbund (MVV) and Stadtwerke Landshut to manually create the transit schedule. However, it was not feasible to do it as we have more than 500 transit line routes within the proposed study area (see Chapter 5). Therefore, an option with GTFS was chosen.

General Transit Feed Specification (GTFS) was created and provided by Dr. Carlos Llorca Garcia from the Assistant Professorship of Modeling Spatial Mobility at Technical University of Munich. Data used to formulate GTFS was retrieved in the form of CSV file. The given data recorded most of public transport stop points in MMR. Due to the different patterns of each line routes, the following assumptions were made to facilitate the study process:

- 5 minutes for U-Bahn
- 10 minutes for tram and bus in core city
- 15 minutes headway for bus in small city
- 20 minutes headway for S-Bahn and bus in rural city
- 30 minutes for regional train
- Operation time from 4h00 to 22h00 without peak or off-peak time
- Daily Schedule

It is true that some assumptions do not reflect the actual schedule. For instance, U-Bahn does not run with a constant headway of 5 minutes from 4h00 to 22h00. However, for convenience, it was decided to assume constant headway for all line routes. Moreover, there are 1,398 line routes in MMR created for GTFS. Considering a proper schedule of each line route, the creation task would be very time-consuming as each line route has its own specific number of vehicle journeys, different headway for morning peak and evening peak, and different schedule for weekdays and holiday. Besides, data used to create GTFS was generated through Google API, and thus some data for regional bus was not accurate either. For the instruction on how to create GTFS, the information can be referred to: https://developers.google.com/transit/gtfs/reference/

4.3 Geospatial data

Geospatial data used in VISUM was downloaded from Geofabrik, a geodata distributor of Openstreetmap. Before the data can be used to model the travel demand, some networks had to be cleaned to fit the model resolution. The resolution of the study is at the district level. Hence, the residential and unclassified streets are not considered in the model. However, it was later decided to include residential and unclassified streets in the model as the analysis proved that many disturbances on transit line routes have been occurred. An example for it is the line routes of bus has to be bundled in the other road levels (e.g., primary and secondary). To clean the network, a few tasks were undertaken through OSMOSIS, a command line Java application for processing OSM data.

Firstly, the downloaded geodata was geographically cut using the polygon command against the boundary of study area. Secondly, some unwanted links and nodes were discarded by using the pipeline control task. An example of command used to assess OSM data is illustrated in following Figure 4.1.

Figure removed due to possible copyright infringements

Figure 4.1: OSM Data Manipulation Task
Source: OSMOSIS Detailed Usage 0.46

Chapter 5

Study Area

Munich is the capital city of German state of Bavaria. The city is the third largest city with high density of inhabitants after Berlin and Hamburg. Munich is well-known for its automobile industry as a city itself is a major economic center in southern Germany. In terms of metropolitan status, Munich Metropolitan Region (MMR), one of the eleven metropolitan regions in Germany, principally consists of Munich and its surroundings. MMR is currently a home to more than 5.2 million people (Metropolregion München, 2015). In 2016, it was reported that more than 368,000 commuters traveled daily to work in Munich from its surroundings (Planungsverband Äußerer Wirtschaftsraum München [PV], 2016). To avoid any confusion between Munich and the district of Munich, I decided to referred the capital city as Munich City and district of Munich as Munich.

5.1 Selection of study area

This section explains how study area in the research is determined. As previously discussed in Chapter 1, Section 1.3, the objective of the thesis is to investigate any possible impacts of Erding Ring Closure on passenger flows. It is worth noting that the goal of Erding Ring Closure Project is to improve the airport access as well as the transit connection in Erding. Therefore, the main criteria in defining the planning area for this thesis are limited to the following criteria:

- Data availability
- Commuter Data to Munich City, Freising, and Erding
- Travel survey of commuter to Munich Airport
- Location of Erding Ring Closure, S-Bahn S1, and S-Bahn S8
- Socioeconomic and demographic data
- Other constraints (e.g., time constraint for the whole research)

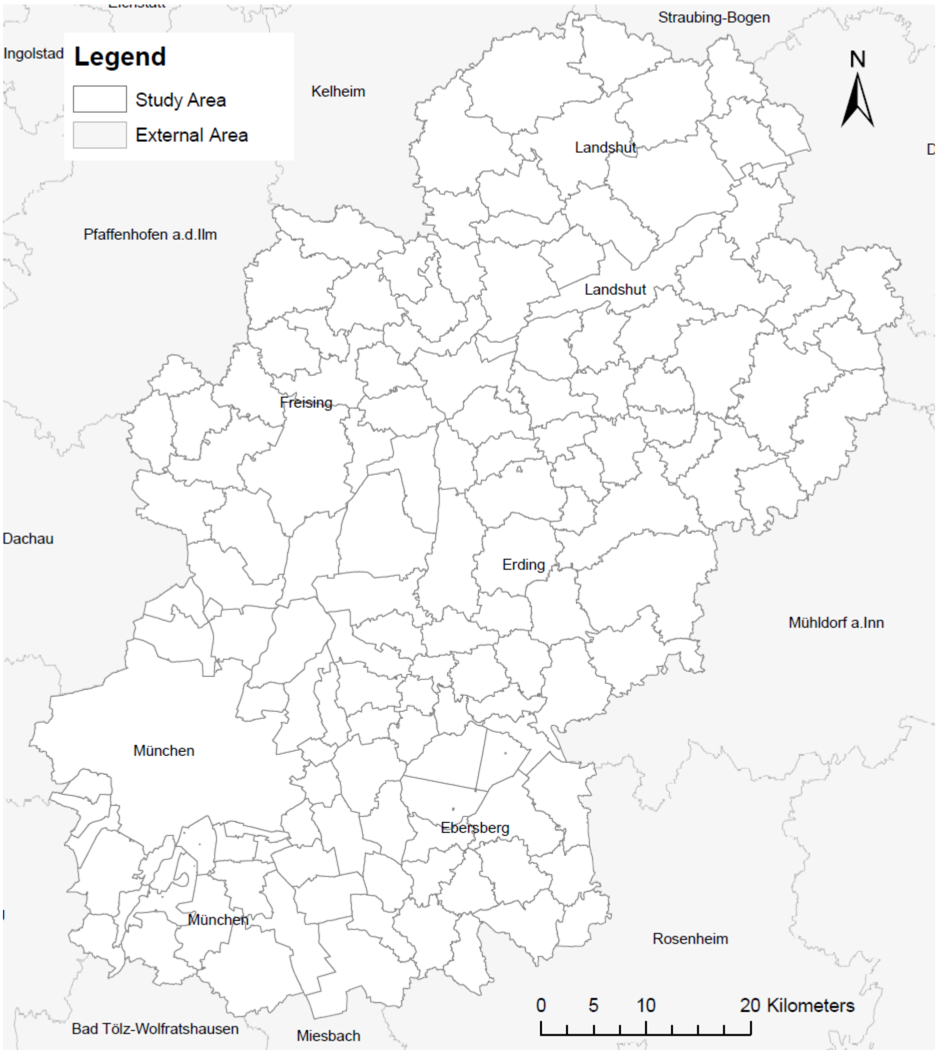

Figure 5.1: Study area for this research
Source: Openstreetmap and elaborated by author with ArcGIS

Among many potential locations, the choice of two urban and five districts (as shown in Figure 5.1) for the study was influenced by their high share of commuting trips to Munich City, Erding, and Freising. Another more plausible account of the reason to select them is the trips to airport. To elaborate upon the main criteria, I have made an assumption regarding the number of commuters to Munich City. A quick analysis is carried out to support select the data relevant to study's purpose. It should also be noted that the selection process is limited to the available data provided by the Assistant Professorship of Modeling Spatial Mobility (MSM).

At first step, districts with the number of daily commuters to Munich City lower than 10,000 will be discarded. Data generated by Federal Agency for Employment (German: *Bundesagentur für Arbeit [BA]*) in 2016 recorded the districts with daily commuter with social insurance to Munich City. Based on the statistics, only 7 out of 27 available urban and districts has the number of commuters more than 10,000. These 7 districts are Dachau, Ebersberg, Erding, Fresing, Fürstenfeldbruck, Munich, and Starnberg.

The selection of study area then continued based on the assumption that if there is no significant changes on current travel times from any districts to airport or changes on passenger flows at certain station, that districts will be excluded. Dachau, Fürstenfeldbruck, Starnberg are connected to airport by S-Bahn S1 and S8. By taking travel time as a main indicator, it is obvious that commuters from Dachau, Fürstenfeldbruck, and Starnberg would remain taking S-Bahn S1 or S8 to the airport instead of the new service. The addition of new service to airport lines would not make any changes to the current travel time for them. Importantly, the distribution of passenger loads on 2nd Main Trunk (German: *2.Stammstrecke*) would not change either since the situation remains almost the same. Ebersberg, on the other hand, will now have two choices at the Munich's east station (German: *Ostbahnhof*). Commuters can either take S-Bahn S8 or S2 to airport. Travel time on S-Bahn S2 is perhaps longer by a small margin; however, the passenger flows at Ostbahnhof is evidently like to be influenced by the new service. Therefore, Ebersberg is included in the study area while Dachau, Fürstenfeldbruck, and Starnberg are excluded.

Landshut City and Landshut are later included due to their significant share in passenger survey to airport, as well as its underlying status in the Erding Ring Closure project. The inclusion of Landshut can be partially explained in the context of travel time of Landshut-Messe. Under this context, it is possible that Messe bound commuters are like to go through Erding rather than to travel through Munich's central station (German: *Hauptbahnhof*) when the extended line is put into operation. Apart from the Landshut-Messe situation, the data provided by FMG was also used to help better the decision on Landshut. A survey done by FMG in 2016 showed that the share of passengers from Landshut is significant higher compared to other districts in the region. Thus, it makes Landshut City and Landshut applicable for the study area.

5.2 Current situation of urban mobility

This section briefly describes the current situation of urban transport and mobility in the study area. However, there is no available data for Landshut City and Landshut. Therefore, only 5 urban and districts are discussed in the context of urban mobility. Moreover, the average value is used to explain the current situation instead of using each value from each district. Those values can be found in car ownership chart, car availability chart, and accessibility to workplace chart.

Data generated by the Mobility in Germany (German: *Mobilität in Deutschland [MiD]*) in 2008 found that the districts within the study area have higher rates of car dependency than average, with longer commuting distances and a spread out urban structure (MVV, 2010a,b,c,d,e). Using data from MiD for a mode share analysis of the districts in study area, the report provides an interesting insight into the share of travelers using a particular mode of transport, as shown in Figure 5.2 below.

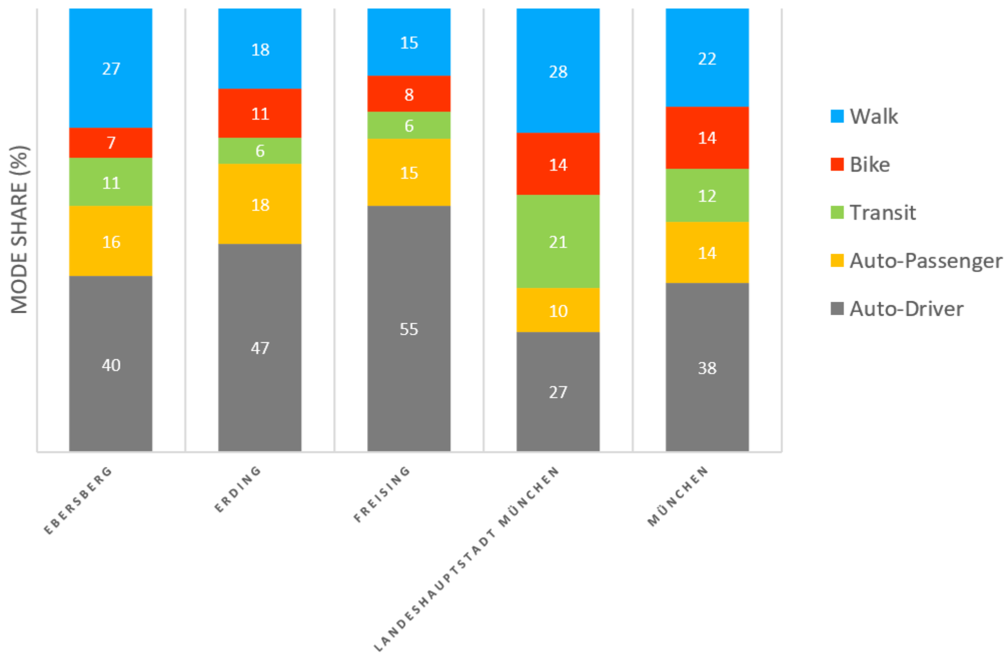

Figure 5.2: Modal Split in districts within study area
Source: Mobility Reports from various MVV Reports, 2010a,b,c,d,e

Figure 5.2 shows the modal split in 2008, and by far private car is the most frequently used means of transport. With the exception of Munich City, it appears that the shares of private vehicle from other districts are higher than 50% (sum of auto-driver and auto-passenger). According to MVV (2010), the report highlighted that walking and cycling have important roles in daily mobility, however most of this is concentrated in the city.

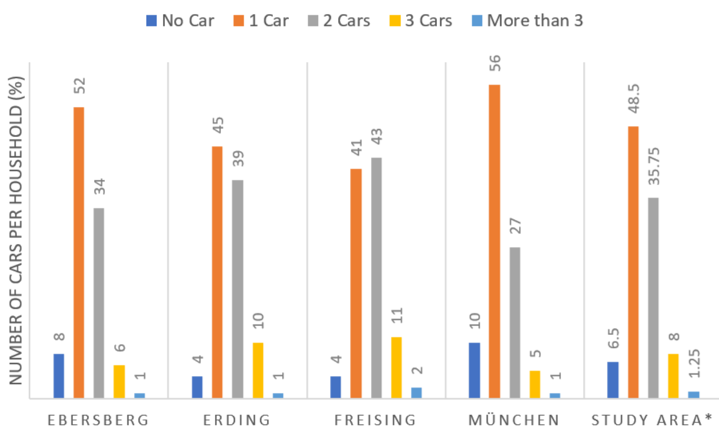

Figure 5.3: Number of car per household
Source: Mobility Reports from various MVV Reports, 2010b,c,d,e

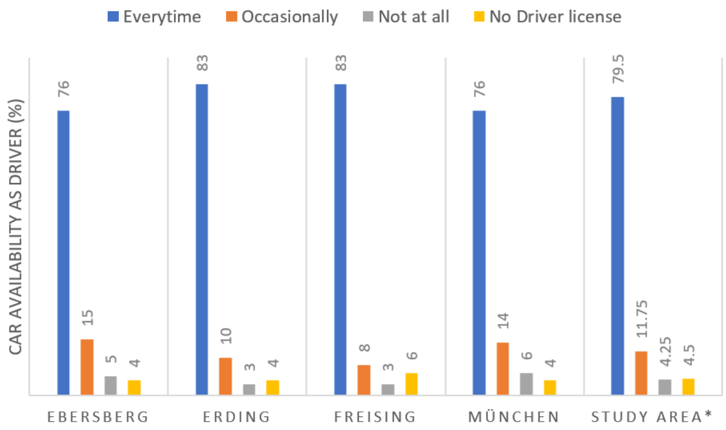

Figure 5.4: Car availability as a driver
Source: Mobility Reports from various MVV Reports, 2010b,c,d,e

Figure 5.3 and Figure 5.4 provide additional information on modal split within the study area. In average, the car ownership bar chart shows that only 6.5% households do not possess a car compared to 93.5% households with cars, in which 48.5% households having access to one car. In other words, every household in study area has an average of 1.4 cars (MVV, 2010b,c,d,e). Notably, the high car ownership also proves that commuting with private car is the most popular choice within the city, and only those who possess no driver license cannot access a car. This can partially be explained by the sparser public transport coverage outside the city, the reduced flexibility buses offer, and the fact that cycling and walking are not competitive with the comfort provided by a private car, especially over longer distances or in bad weather.

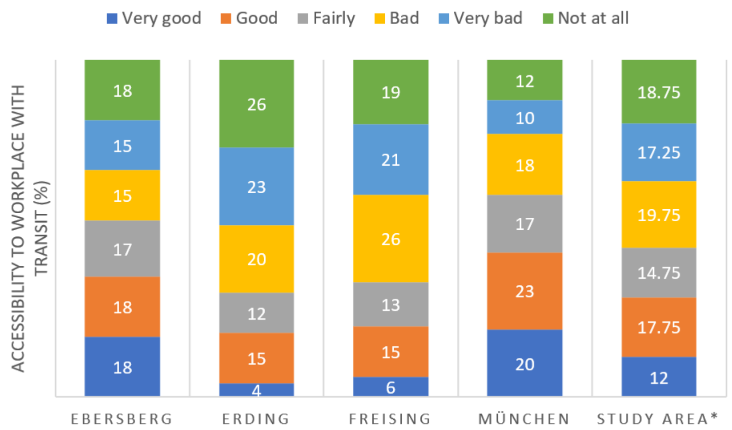

Figure 5.5: Accessibility to workplace with transit
Source: Mobility Reports from various MVV Reports, 2010b,c,d,e

In contrast to the other transport modes, it appears that public transport in study area occupies only 8.75% in mode share (average value with exception of Munich City) based on Figure 5.2, and this number is even lower than both walking and cycling if combined. The fact that public transport is not so widely used within the city provides an initial clue that there may be poor public transit accessibility or service in these areas. It is likely that individuals use private car over the public transport for short-distance trips. As further proof of this, Figure 5.5 provides additional information regarding residents' accessibility to their workplaces by public transport. It shows that 55.75% of commuters rated the accessibility to their workplaces by public transport as bad, very bad, or as not at all. According to the interviews conducted by MVV, commuters would like to see some significant improvements of public transport (MVV, 2010b,c,d,e). Should there be an improvement, commuters may swap their private car trips for public transport trips in the city, especially where distances are short.

5.2.1 Road Network

The road network in the study area comprises of five autobahn (i.e., A92, A93, A94, A99, and A8). As of 2016, autobahn network in Germany has a total length of about 12,993 km, in which 2,515 km is in Bavaria (Statistische Ämter des Bundes und der Länder, 2016). Most sections of autobahns contain two, three, or sometimes four lanes with an additional of emergency lane. There are also some other sections that remain in an old state, with two lanes and no emergency lane.

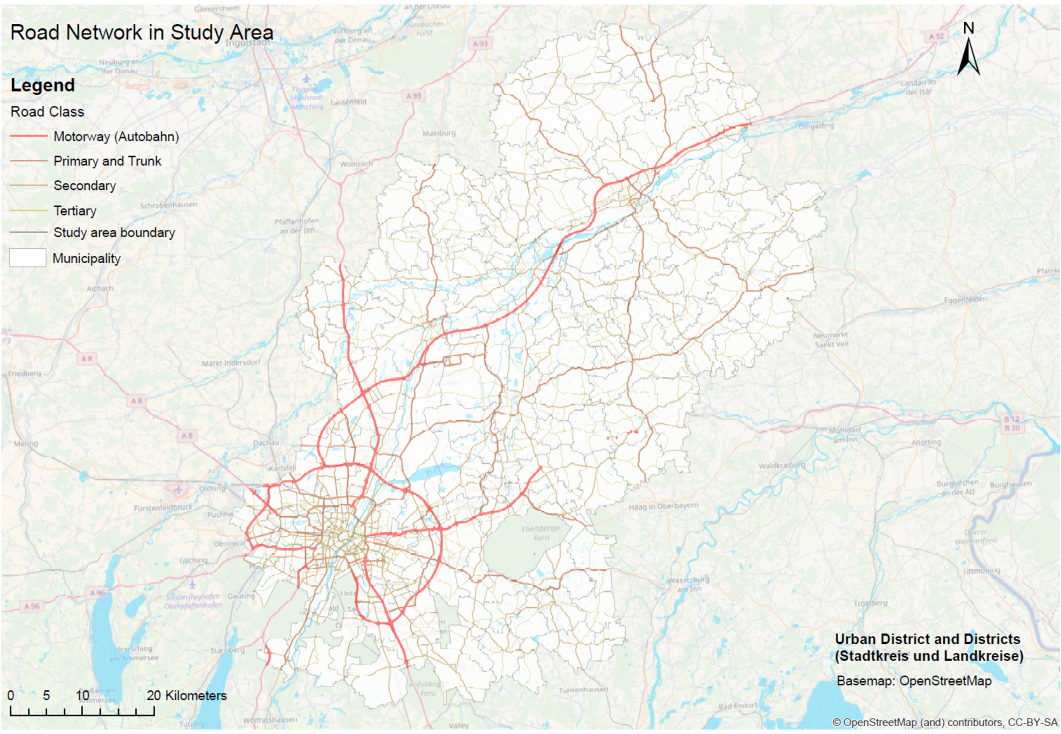

Figure 5.6: Private network within study area
Source: Openstreetmap and elaborated by author with ArcGIS

From Figure 5.6, Munich City has the best connection compared to other districts in study area. The ring road, A99 provides a better access for car to other motorways. Ebersberg and Erding are the only two districts that are not connected by autobahn. Indeed, these two districts are connected by federal highway B301 and B388 respectively. Besides, it seems that access to airport by road network is well-established. Airport can be reached by A92 and B301 on the western corridor while a number of local road networks on the the eastern side.

5.2.2 Public Transport Network

Public transport in Germany is operated by different transit authorities, depending on where they locate. For instance, Münchner Verkehrsgesellschaft (MVG) is a municipally owned company that operates U-Bahn, tram, and city bus in Munich City. MVV, on the other hand, is a transit authority of Munich City. MVV does not provide any transport service, but coordinate transport and fare in and within surrounding areas of Munich City. Transport services are indeed provided by 40 companies under the supervision of MVV (MVV, 2015). For example, S-Bahn is solely operated by S-Bahn München, a subsidiary of Deutsche Bahn (DB). In Landshut, Stadtwerke Landshut is the main transit authority of the city that operates city bus, express bus, and airport express. On regional level, DB provides all the service of Regio Bahn throughout the whole country.

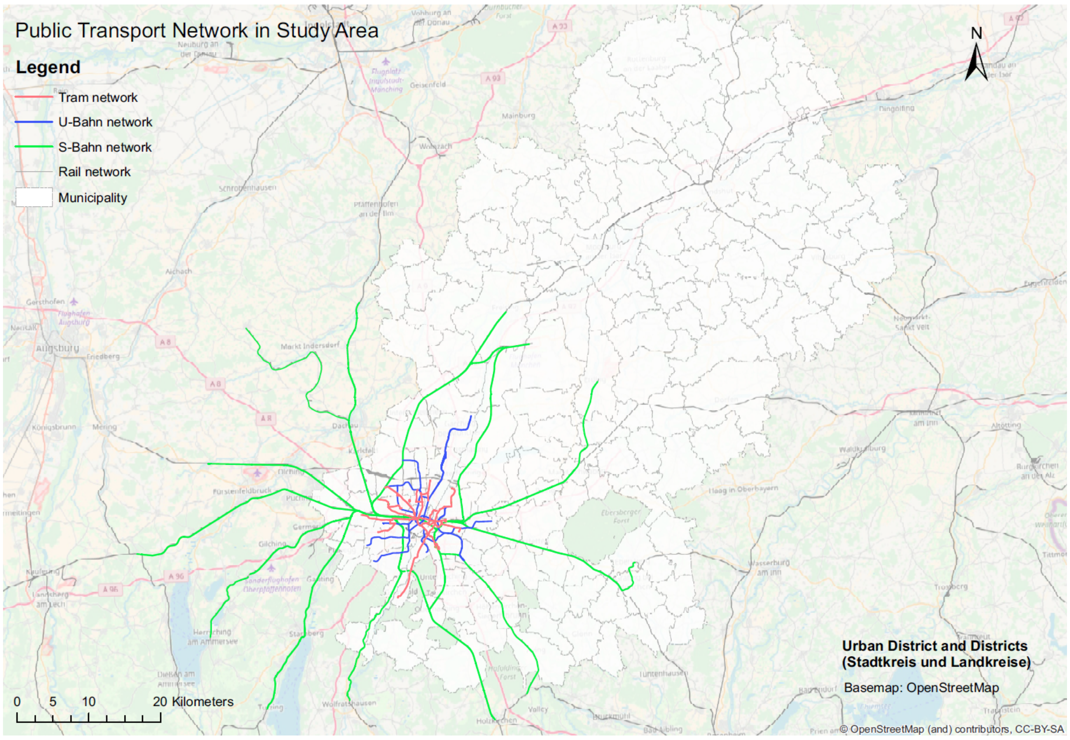

Figure 5.7: Public Transport in districts within study area
Source: Openstreetmap and elaborated by author with ArcGIS

Based on Figure 5.7, Munich City and Munich have the most well-integrated public transport network with most stations are multimodal stations. In terms of rapid transit connection, a total of 8 S-Bahn lines are in operation with 8 branches on western side and 5 on the eastern side. Today, the S-Bahn covers most of the populated area of the Munich Metropolitan Region, connecting most cities in surrounding districts. The airport is connected to the capital city by S-Bahn S1 and S8. The journey to airport from Erding with S-Bahn is not possible as the last stop of S-Bahn S2 terminated in Erding. However, the city is connected to airport by regional bus which operates with 20 minutes headway, depending on the peak time. The connection between Landshut and airport is bridged by airport express line and regional train service with additional transfer in Freising.

5.3 Analysis of travel times

A discussion of relative travel time is made in addition to the current situation of mobility in study area. It may be worth noting that the Erding and Landshut have the most poor public transport connection compared to other districts in the study area. Performing the travel time analysis resulted in contour maps of both isochrones.

While these isochrones can be used to make judgements about the temporal accessibility via a certain mode, they are not as helpful for identifying areas where public transport are uncompetitive with private car. For this analysis, mapping the relative travel time of public transport against that by car is more helpful to visualize areas that require improvement. Figures 5.8 and Figure 5.9 show this relative travel time by public transport and car respectively.

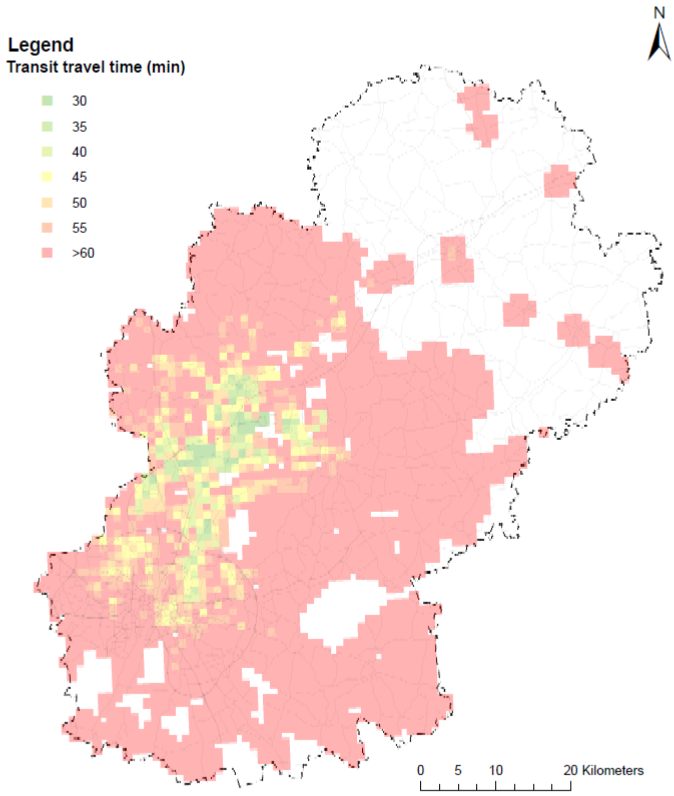

Figure 5.8: Transit travel time to airport in minutes
Source: Google Maps and elaborated by author with ArcGIS

Figure 5.8 presents the travel time with public transport to the airport. It appears that almost entire area of Landshut have no transit access or poor access to airport, except for Landshut City and other small towns along the rail corridor. The journey to airport from Ebersberg and Erding would take between 75 to 169 minutes (based on Google Maps) which is considerably high, twice the amount of travel time from Munich City to airport. The figure above also highlights the short travel time along S-Bahn S1 and S8 lines to airport. Those who live anywhere close to S1 and S8 lines can reach airport within or less than an hour.

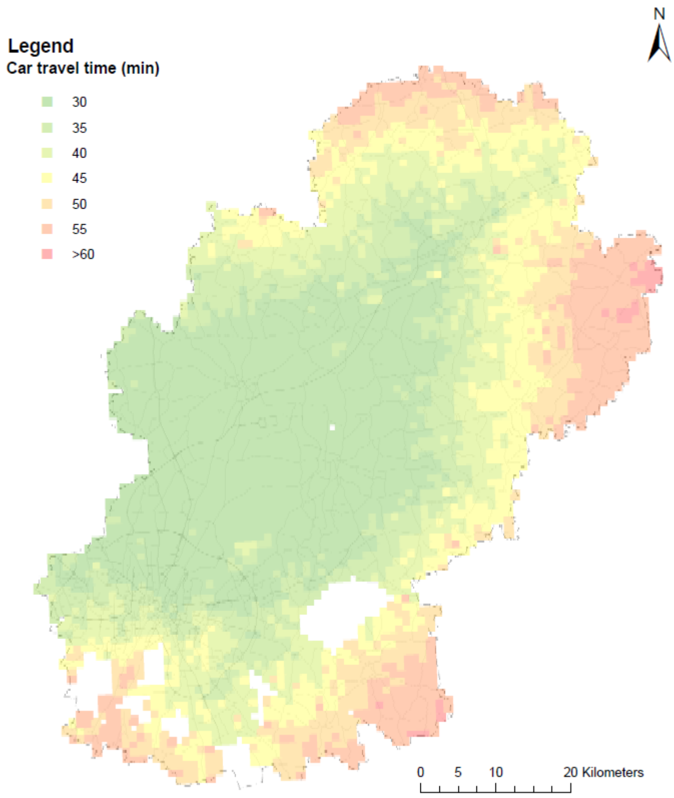

Figure 5.9: Car travel time to airport in minutes
Source: Google Maps and elaborated by author with ArcGIS

While public transport is more competitive in the city center and southern half of Munich, it is broadly uncompetitive in the northeast of Munich, with the worst areas lying from Erding to Landshut. In analyzing the Figure 5.9, it is generally said that private car is more competitive than public transport. While the journey to airport with public transport takes at least 79 minutes, travelers from Erding and Landshut can reach the airport within 30 minutes by car. In contrast to public transport, it seems that travelers from Landshut can access the airport with private car regardless of where they live.

5.4 Transport Analysis Zone System

Defining the zone system is an essential element of the transport modeling framework. The zone system in rural area is designed to be larger than the zone in urban area. The TAZ is created by MSM through the rasterization method by Moeckel and Donnelly (2015). The zones for study area are made up of 2,796 zones across five districts and two urban. Both Figure 5.10 and Figure 5.11 show the zone of the study area.

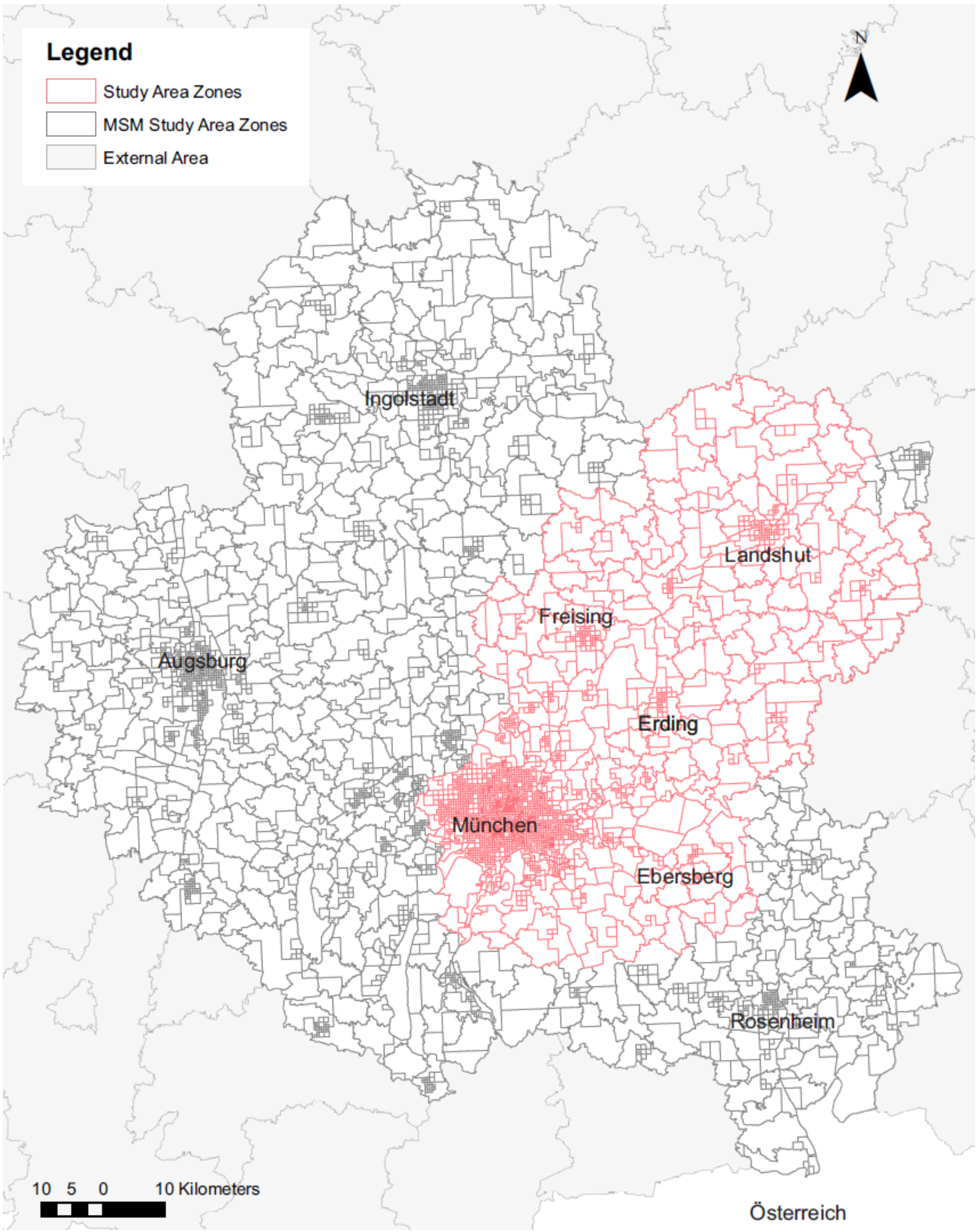

Figure 5.10: Traffic zones of study area within MMR
Source: MSM and elaborated by author with ArcGIS

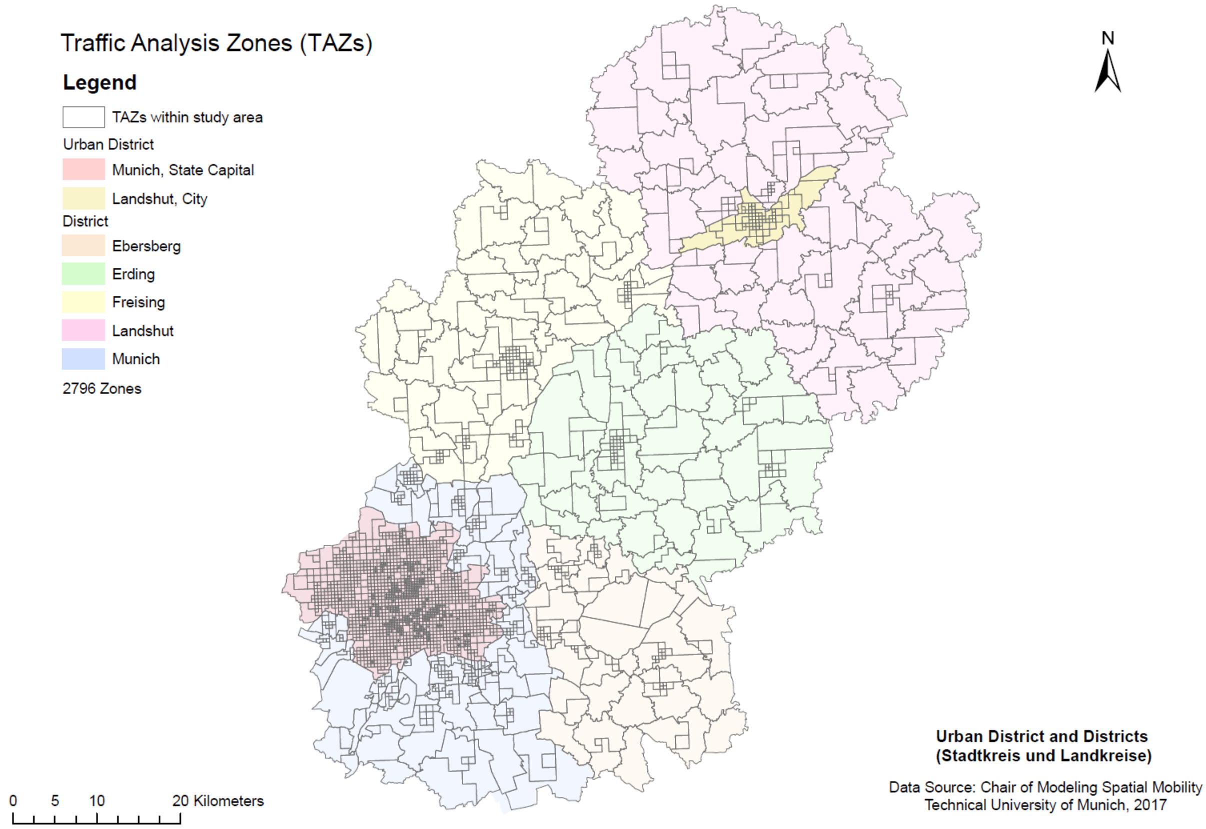

Figure 5.11: Traffic zones of study area
Source: MSM and elaborated by author with ArcGIS

5.4.1 Airport Zone System

Due to the predefined raster cells, four raster cells are found to be adjacent with airport area. Therefore, to apply and analyze the scenarios in this area, four zones surrounding the airport are modeled as airport zone.

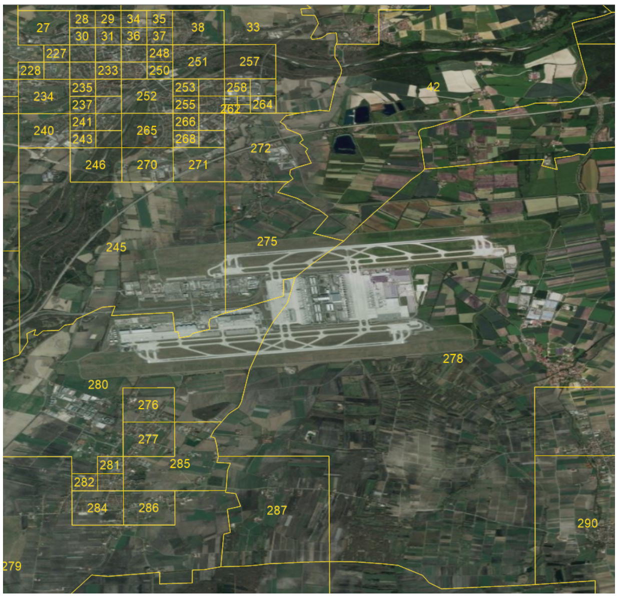

Figure 5.12: Zone system of airport
Source: MSM and elaborated by author with VISUM

Chapter 6

Modeling Framework

6.1 Model Specification

The specification of the model used for this study is described in this section before the estimation process. This section involves specifying the choice set, explanatory variables, and model structure. As stated in Chapter 1, the choice set was decided to be auto and transit.

6.1.1 Variables considered

As described in Section 2.2.3, the traveler's preference of alternative choice sets can be predicted by adopting the utilities of the alternatives, and these utilities are in turn governed by various explanatory variables. Hence, it is necessary to determine which variables should be included in the design once the alternatives has been decided upon. According to Ortúzar & Willumsen (2011), the variables used to determine the choice of transport mode are normally based on socioeconomic factors, trip characteristics, and transport facility characteristics. Although it may have been possible to include all these variables, it was decided to use only specific variables related to transport facility. This includes specific travel time and cost variables. However, it would be difficult to create common variables for most of the variables included. Main reason can be referenced to a number of the attributes that only pertained to one alternative. An example of which is the number of transfers in public transport. This attribute is obviously only relevant for explaining the public transport and not the car. Finally, to make the model more manageable, efficient and balanced, only five variables are assumed for each of the alternatives. Some variables included are adopted from previous studies that yielded results with high validity while the specification of some variables are created based on a couple of assumptions.

Auto access and egress time

The reason to create access and egress time as a separate variable was based on several pieces of information. Moeckel et al. (2015) noted that the coefficient of out-of-vehicle time is twice as negative as the coefficient of in-vehicle time. This is mainly because the times spent outside vehicle were perceived as burdensome than the travel time in vehicle. As for auto, access time refers to the time spent to access the vehicle, and this also includes the walk time to the garage or parking lot. Access time is assumed to be 2 minutes in this study. Clearly, this value is quite low for some areas where travelers walk from home to the parking lot to access the vehicle. In most cases, however, 2 minutes is deemed reasonable as travelers usually park their own vehicle right in the garage or in front of the house. On the other hand, egress time refers to the time spent to walk from the parking location to the final destination. Egress time varies greatly according to the location of the final destination. In urban areas, egress time is somewhat high compared to the suburban and rural areas where travelers can park right in front of the destination (Moecket et al., 2015). In this study, 5 minutes is chosen for the variable, which is fairly high but reasonable. The attribute used was based on those used in the mode choice study conducted by Moeckel et al. (2015).

Travel time by car

Travel time generally represents the level of service (LOS) of transport mode in the network. In this study, the absolute fixed value of travel time by car could not be used due to the wide range of travel times included in the design. Indeed, the travel times by car were estimated by using VISUM. To estimate the travel times, first the generated OD matrices (previously described in Chapter 4) were allocated into its TAZs. Then VISUM calculated the travel times and depicted it in the form of skim matrix. Using Google Map to engineer the travel time is also possible; however, it was decided not to use it due to the extremely time-consuming process.

Auto operating cost

Operating cost normally covers gas price, maintenance, insurance, tax, and other costs associated with car usage. It was decided to use operating cost variable, which includes the average fuel consumption cost per kilometer, fixed costs (insurance and tax), and variable costs (maintenance). The fixed value used as the reference was adopted from the report prepared by the Allgemeiner Deutscher Automobil-Club e.V. (ADAC) (2017). The report provides the average all inclusive driving cost of over 1900 vehicle models. For this study, the value of operating cost was 0.47 EUR/km, which was the median value.

Parking cost

In contrast to operating cost, it is difficult to define metered parking fee as it differs considerably depending on the location. The parking fee was initially modeled based on the parking rate in Munich's city center, which is 0.50 EUR per 12 minutes. Considering the case of commuting trip, if the vehicle were at the parking place for 8 hours, the resulting parking fee would be 20.00 EUR. Clearly, this makes the parking fee more dominant in the model. Therefore, the parking fee rate of 0.50 EUR per 12 minutes was not used. To tackle these obstacles, it was decided to adopt the value of parking fee based on two parking studies in Germany and England conducted by Axhausen & Polak (1991). The fixed absolute value of parking fee are assumed to be 2.00 EUR for general parking places. In terms of parking fee at airport, it was decided to use 64.00 EUR which is the parking fee for two days. The reason for it is because air passenger tend to stay longer at the final destination. Hence, considering at least two days of parking seems to be convenient for the study. In order to be able to ensure the consistency, Moeckel et al. (2015) suggested to divide parking cost equally for outbound and return trip. This is because the travel time and cost are accounted for one way only.

Transit access and egress time

Similar to auto access and egress time, the transit access and egress time were created as separate variables from travel time. As for transit, access time refers to the time spent outside the vehicle, which includes the walk time to platform or gate. With regards to egress time, it refers to time spent from the platform to the final destination. In contrast to auto access and egress time, the value of access and egress time for transit were estimated with VISUM. Both times were calculated and represented by skim matrices in VISUM.

Travel time by transit

Generally, travel time by transit is measured with references to its components. This includes access time, in-vehicle time, origin wait time, transfer wait time, and egress time. However, since the access and egress time were separate variables, travel time could be measured in terms of origin wait time, transfer wait time, and in-vehicle time. To estimate the travel time by transit, the same approach used for access and egress time was applied. Firstly, all of its components - origin wait time, transfer wait time, in-vehicle time were calculated by VISUM. The results showed that transfer times were significantly higher than actual time (using Google Maps), whereas origin wait time was zero value for any given trip. This irrationalities could have been caused by GTFS data used to create transit schedule. A couple of assumptions were made in GTFS, and some assumptions did not reflect the actual schedule. An example for it can be referenced to the one headway for both peak and off-peak time. In light of this obstacle, in-vehicle time was assumed as travel time by transit.

Number of transfer

Similar to access and egress time, VISUM generated the number of transfer according to the network pattern. Absolute value for this variable could not be used since the given trip were made for different destinations, thus makes it difficult to assume one fixed value.

Transit Fare

Along with travel time, the cost associated with a transportation mode, or transit fare, has major impact on mode choice (Ortúzar 2000; Vuchic 2005; Ahern & Tapley 2008; Twaddle, 2011). The transit fare for the public transport for the study was adopted from report prepared by Verband Deutscher Verkehrsunternehmen (VDV) (n.d.). The reference of the fare was calculated based on the rate of 2.10 EUR per 5.9 kilometer, and the resulting fare per kilometer is 0.35 EUR. The cross-check with MVV Tariff Structure for single journey trip was also attempted. The calculation showed similar results with minor difference.

Summary of variables considered

Table 6.1 provides a summary of variables that were discussed in previous sections.

Table 6.1: Variable considered in the estimation

		Trip characteristics	
Mode	**Variable**	**Specification**	**Source**
Auto	Access time	2 min[1]	Created for the experiment
	Egress time	5 min[1]	Moeckel et al. (2015)
	Travel time	-	Generated by VISUM
	Operating cost	0.47 EUR/km[2]	ADAC (2017)
	Parking cost	2 EUR, 64 EUR[3]	Axhausen & Polak (1991)
Transit	Access time	-	Generated by VISUM
	Egress time	-	Generated by VISUM
	Travel time	-	Generated by VISUM
	Number of transfer	-	Generated by VISUM
	Transit fare	0.35 EUR/km[4]	VCD (n.d.)

[1] Fixed value
[2] Average fuel consumption cost
[3] 2 EUR for general parking locations, 64 EUR for airport
[4] Converted from 2.10 EUR/5.9km

6.1.2 Utility equations

The preferred modeling framework is disaggregate discrete choice model. The main assumption is that trip-maker tries to maximize personal utility and selects the alternative with the highest utility. As described in Section 2.2.3, the utility function of two alternatives can be formulated as follows:

$$\begin{aligned} U_{Auto} &= V_{Auto} + \varepsilon_{Auto} \\ U_{Transit} &= V_{Transit} + \varepsilon_{Transit} \end{aligned} \tag{6.1}$$

The corresponding deterministic part V of the alternatives expressed as the sum of the explanatory variables and unknown β parameters are formed as follows:

$$\begin{aligned} U_{Auto} &= C + \beta_{OVT} * access\ time + \beta_{IVT} * travel\ time \\ &+ \beta_{OVT} * egress\ time + \beta_{AOC} * travel\ distance * operating\ cost \\ &+ \beta_{PC} * parking\ cost * 0.5 \\ U_{Transit} &= C + \beta_{OVT} * access\ time + \beta_{IVT} * travel\ time \\ &+ \beta_{NTR} * number\ of\ transfers + \beta_{OVT} * egress\ time \\ &+ \beta_{TRF} * travel\ distance * transit\ fare \end{aligned} \tag{6.2}$$

6.1.3 Unknown β parameters

The review of literature with regards to the unknown parameters in Section 2.2.8 has provided a guideline to select model parameter in the case of very limited data availability. It was decided to assume the parameters from mode choice study conducted by Moeckel et al. (2015). It is worth saying that the parameters are heuristically derived parameters. The main decision to use these parameters was due to the lack of data availability in MiD. In particular, MiD offers a wide range of travel information in both urban and suburban areas for the whole Germany. However, MiD lacks specific data associated with travel time (i.e., access and egress time). This shortcoming thus makes MiD inapplicable for this study. Table 6.2, Table 6.3, and Table 6.4 summarizes the adopted parameters and constants.

Table 6.2: Coefficients for utilities of auto

Coefficient	**Description**	**Personal**	**Commute**	**Source**
β_{OVT}	Out-of-vehicle time coefficient for auto: parameter evaluating the travel time spend out of vehicle	-0.036	-0.050	Moeckel et al. (2015)
β_{IVT}	In-vehicle time coefficient for auto: parameter evaluating the travel time spend in a vehicle	-0.018	-0.025	Moeckel et al. (2015)
β_{AOC}	Auto operating costs coefficient	-0.008	-0.007	Moeckel et al. (2015)
β_{PC}	Parking costs coefficient	-0.012	-0.010	Moeckel et al. (2015)

Table 6.3: Coefficients for utilities of transit

Coefficient	**Description**	**Personal**	**Commute**	**Source**
β_{OVT}	Out-of-vehicle time coefficient for transit: parameter evaluating the travel time spend out of vehicle	-0.036	-0.050	Moeckel et al. (2015)
β_{IVT}	In-vehicle time coefficient for transit: parameter evaluating the travel time spend in a vehicle	-0.018	-0.025	Moeckel et al. (2015)
β_{NTR}	Coefficient on number of transit transfers	-0.01	-0.01	Moeckel et al. (2015)
β_{TRF}	Transit fare coefficient	-0.012	-0.010	Moeckel et al. (2015)

The utilities are estimated against a base alternative. In the model, if one alternative was chosen as the base alternative, its constant has to be set to zero. It is important to note that the constants in Table 6.4 are used as a reference point. The calibration of the constants is later required to estimate the accuracy of model fit.

Table 6.4: Constant for auto and transit

Constant	**Description**	**Personal**	**Commute**	**Source**
C	Constant Auto	0.46 to 0.58[1]	-0.51 to -0.20[1]	Moeckel et al. (2015)
C	Constant Transit	0.52	0.30	Moeckel et al. (2015)

[1] Distinguished by auto occupancy

6.2 Model Building in VISUM

A model in VISUM was developed by following the task described below. For this section, the reader is assumed to have a basic understanding of VISUM. Otherwise, the explanation of software can referred to the user manual. To obtain a better understanding of the software, this section is supplemented by the screenshots showing how VISUM was configured. This can be found in Appendix.

Initial setup

VISUM was opened, and a new project file was created. Selection of 4-Steps model was then confirmed in demand setting window.

Person Group

Mobility behavior of road users varies significantly from age to occupation and to other constraints (e.g., possession of driving license or vehicles). Basically, road users with similar mobility behavior are grouped together and broken down into socio-homogeneous group. For instance, person groups are commonly formed based on characteristics and occupations of road users. In this model, people who are employed can be grouped into a group called EMP and the rests are formed as POP.

Activity Pair

Trip purposes and activities in certain locations are pre-assumed to be the main cause for a particular movement. People move and travel to perform certain activities, and this explains the relation between activity and mobility. Work, School, Leisures are some of activity examples. Activity Pair is formed as a consequence of two successive activities in daily routine (PTV VISUM Manual, 2017). Three activity pairs were created, namely HO, HW, and HA (previously discussed in Chapter 3 and 4).

Demand Strata

Demand stratum links one or several person groups with activity. The combination of person groups and an activity forms a basic demand object which is mainly used in almost calculations of the first three steps. For example, the demand stratum "HW-EMP" represents the group of employees going to work.

Demand Matrices

Matrices were generated from the dataset (as described in Chapter 4). Matrices were imported to VISUM by using AddIn tools in Script setting window. Three demand matrices were created and named as Distribution HA, Distribution HO, and Distribution HW.

Private Transport Network Modeling

The next step to do after all required inputs have been settled is importing the cleaned network into VISUM. Link classifications had been predefined by Openstreetmaps based on German Road Classification. Thus, no extra task on link capacity and speed was exercised. VISUM offers four configurations of resolution to be analyzed, ranging from very detailed to a simple one. At first attempt, urban network setting was modeled. However, there was an error with bus line routes as it could not be bundled into the network, and hence false line routes were created instead. Later, it was decided to model detailed urban configuration, and the results has been improved though some false bus line routes still remain there.

Transit Timetable

GTFS was imported into VISUM through AddIn in Script setting window. Because a single line route requires certain streets and certain stop points, high standard deviation value was given to allow well-established allocation of line routes on certain links in target network. VISUM did not import only the line routes, but also the timetable that has been set up through GTFS. A total of 1,398 line routes with 87,334 vehicle journeys were obtained. A few modifications on timetable were also attempted in order to improve the accuracy of timetable before the analysis.

Zone System

Zone was modeled based on TAZ (as discussed in Chapter 5). Zone, which was retrieved in the form of Shape file, was imported into VISUM and labeled it as zone system. A total of 2,696 zones were made up for the study area. The size of the zone does not matter in VISUM as long as the centrioid are defined.

Connector

Connectors connect the active zone with transport nodes (e.g., stop point, or node on road). There are two types of connectors, private and public connector. As for private connector, maximum length of direct distance was set to 5 km. Public transport connectors was created based on the assumption that traveler has a fair access to stop area within the radius of 1.5 km. Thus, 1.5 km was assumed for public transport connector.

Summary of work done

Table 6.5: Summary of inputs required to run model

Activity pair	**Description**	**Type of trip purpose**	**Person group**	**Demand Stratum**
HA	Trip from home to airport	Personal	POP	HA-POP
HO	Trip from home to other	Personal	POP	HO-POP
HW	Trip from home to work	Commute	EMP	HW-EMP

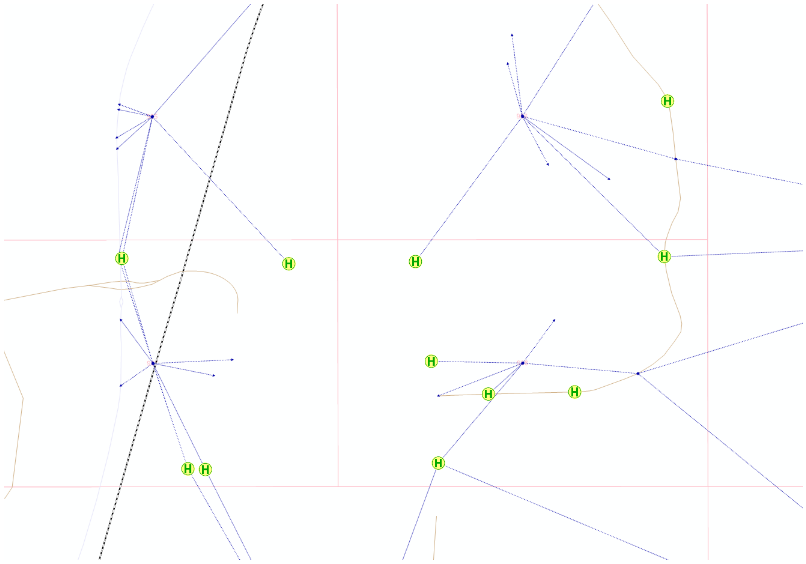

Figure 6.1: Connector configuration in VISUM
Source: Openstreetmap and elaborated by author with VISUM

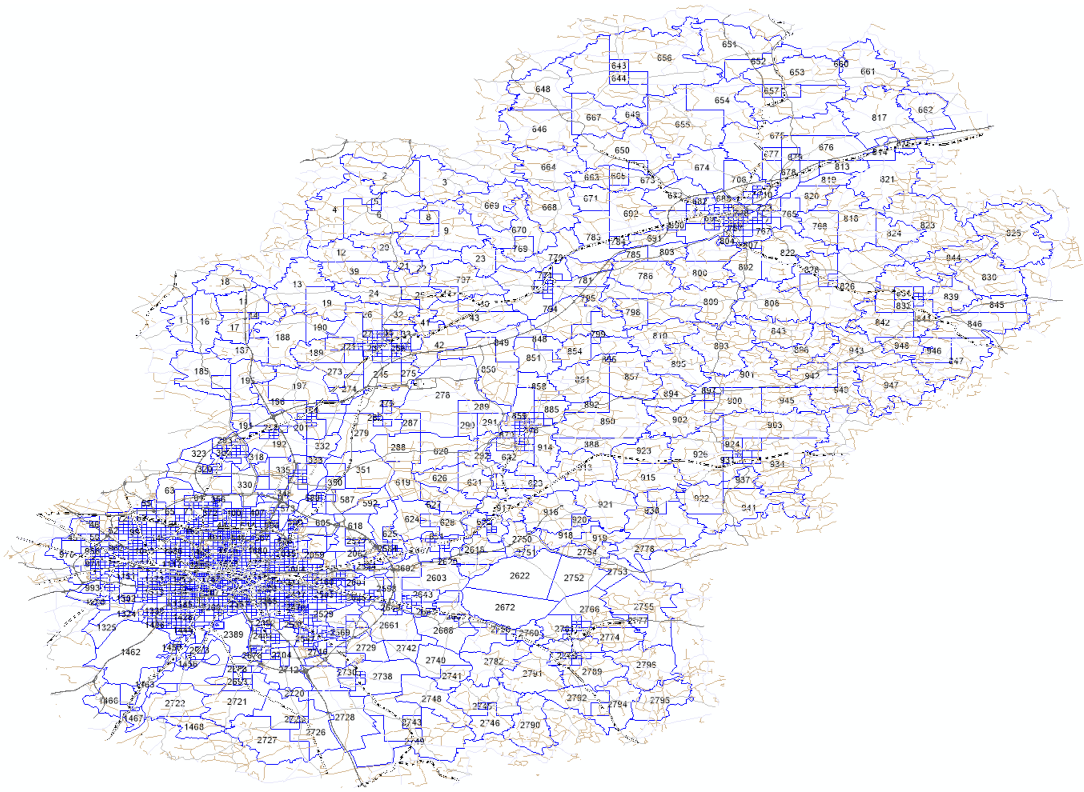

Figure 6.2: Network modeling in VISUM
Source: Openstreetmap, MSM and elaborated by author with VISUM

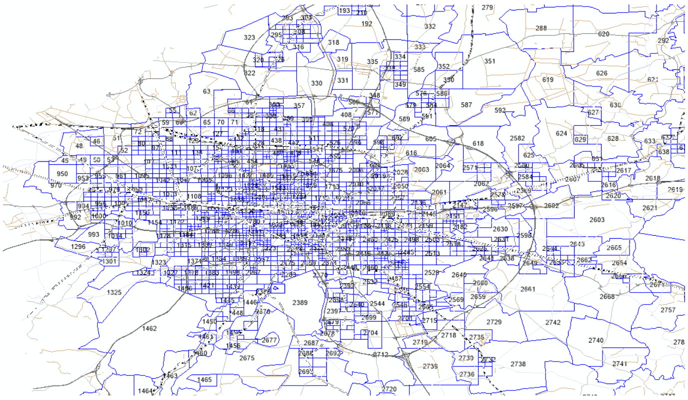

Figure 6.3: An example of network in city center
Source: Openstreetmap, MSM and elaborated by author with VISUM

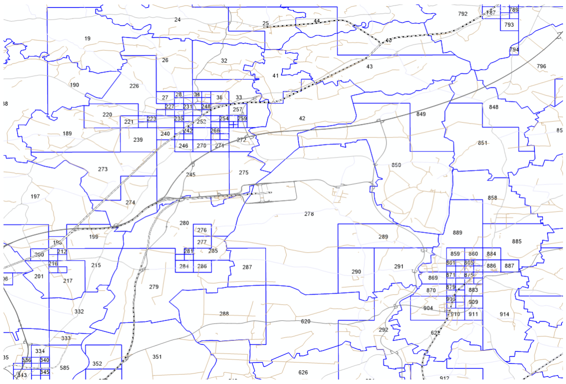

Figure 6.4: An example of network in airport area
Source: Openstreetmap, MSM and elaborated by author with VISUM

6.3 Model Estimation and Results

6.3.1 Estimating mode choice with VISUM

As stated in Section 2.6.2, it was decided to use logit model for this project. Logit model assumes that the error component is independently distributed and type-I extreme value (identically Gumbel distributed). The decision to use logit model was made based on its simple approach and straightforward specification. More importantly, the logit model may be the most suitable for this study because none of the alternatives are deemed to be significantly correlated.

6.3.2 Inputs to VISUM

To simulate mode choice in VISUM, demand stratum of each trip purpose are required. Analysis was exercised in the case of binary choice, and thus trips of each demand stratum were separated between two transport modes (i.e., Auto and Transit). As Figure 6.5 illustrates, data used for the model step mode choice comprises skim matrices, utility function, and demand matrices of each trip purpose. Utility matrices are mainly calculated based on skim matrices.

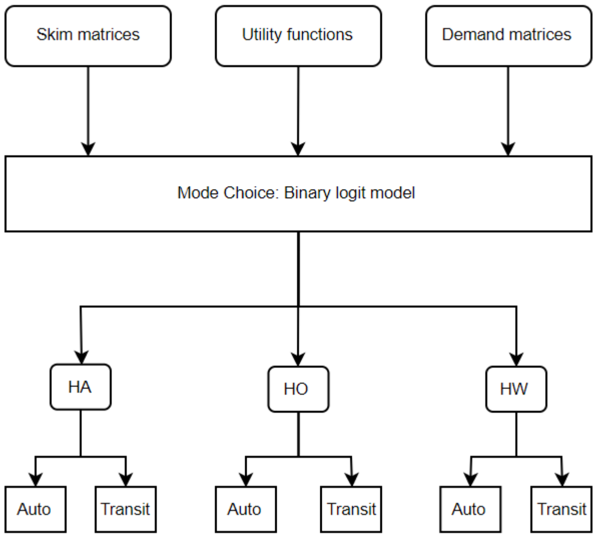

Figure 6.5: Simplified flowchart of mode choice model in VISUM

6.3.3 Simulation results

In this model, auto was chosen as the base alternative, with its constant set to zero. Adopting the constants from Table 6.4 as a reference point, the simulation results highlighted two different results. The derived coefficients appeared to be feasible for airport trip, with only small difference between predicted share and actual share. This could be partially explained by the characteristic of trip to airport, which is often modeled as long-distance travel trip. The parameters in turn was also intended for long-distance travel model. On the other hand, the presented results highlight high deviation of the mean mode shares predicted by the model compared to the actual shares for commuting and other trip. Figure 6.6 and Figure 6.7 compare the results between actual share and predicted share of auto and transit respectively.

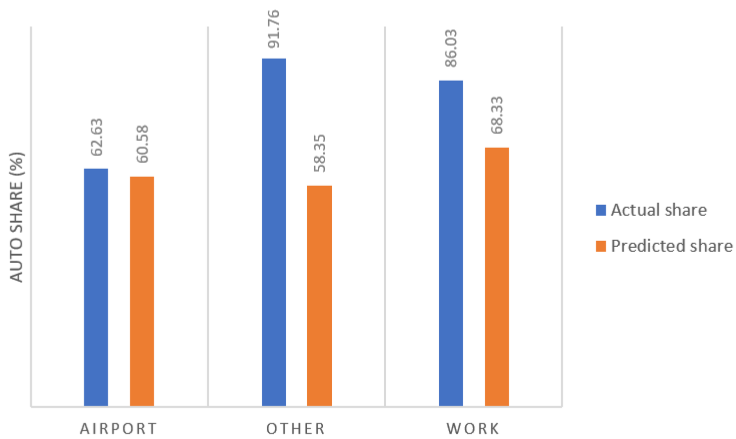

Figure 6.6: Comparison between actual and predicted share of auto

As Figure 6.6 illustrates, the deviation of observed auto shares compared to the actual shares lies within a range of -2% to -30%. An example of it is the trip to other by auto whose predicted share is roughly 33% lower than the actual share.

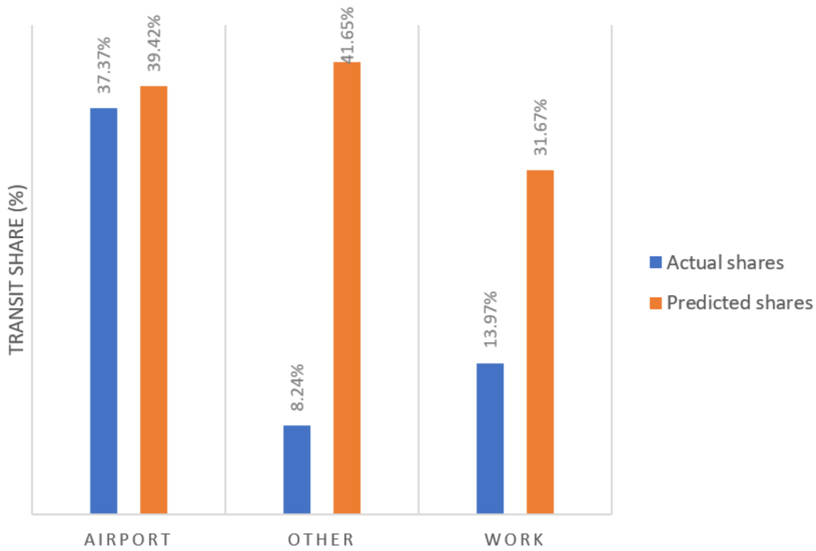

Figure 6.7: Comparison between actual and predicted share of transit

As for transit shares, Figure 6.7 shows the distinct difference between the predicted share and actual share. The difference rates were found to be within a range of +2% to +32%. For example, VISUM predicted the mean mode share of trip to other by transit with 41.65%, which is 32% higher than the actual share.

6.3.4 Calibrated model with new constants

The results with constants adopted from other study suggests that the accuracy of model has not been achieved. Therefore, mode-specific constant was calibrated to find the accuracy of the model fit. Probability of alternatives were predicted for the same model dataset using the same derived parameters from Table 6.2 and Table 6.3. Applying the calibrated constant into the utility functions, the difference rates between mean mode share predicted by model and actual mode share are indicated in Table 6.6, Table 6.7, and Table 6.8.

Table 6.6: Result of a test for accuracy of model fit for Homebased Other

Mode	Actual share[1]	Predicted share	Constant	Deviation
Auto	91.76%[2]	91.77%	0	+0.01%
Transit	8.24%[2]	8.23%	-1.733	-0.01%

[1] Mode share based on MiD (2008)
[2] Modified values

Table 6.7: Result of a test for accuracy of model fit for Homebased Work

Mode	Actual share[1]	Predicted share	Constant	Deviation
Auto	86.03%[2]	86.03%	0	0.0%
Transit	13.97%[2]	13.97%	-0.878	0.0%

[1] Mode share based on MiD (2008)
[2] Modified values

Table 6.8: Result of a test for accuracy of model fit for Homebased Airport

Mode	Actual share[1]	Predicted share	Constant	Deviation
Auto	62.63%	62.63%	0	0.0%
Transit	37.37%	37.37%	0.433	0.0%

[1] Mode share to airport in Bavaria based on FMG (2016)

As shown in the Table 6.6, Table 6.7, and Table 6.8, the mode-specific constants capture the effects of the un-included attributes and measurement errors. Auto has a constant value of 0 because it is the base alternative. Transit has both negative and positive constants for commute, personal (other) and personal (airport) respectively. The calibrated constants for transit are small, which is plausible and desirable.

6.3.5 Estimating Route Choice with VISUM

It was decided to use equilibrium assignment to allocate the private demand on the network. This method was chosen mainly because of its simple approach. Demand matrices with auto were separated into 3 iteration layers with a fixed proportion of travel demand (i.e., 50%, 30%, and 20%). 50 iterations with 20 balancing iteration stages were exercised for each layer to allocate the trips into the road network. Besides, timetable based approach with shortest path search was attempted for travel demand with transit. This method assumed that the passengers are aware of the transit timetable and seek the shortest path to reach their destination.

6.3.6 Inputs to VISUM

Prior to trip assignment procedure, average vehicle occupancy was applied to produce the person car trips. Average vehicle occupancy is determined from the hypothetical travel surveys found in MiD and shown in Table 6.9.

Table 6.9: Average vehicle occupancies according to trip purpose

Average Vehicle Occupancy	Trip Purpose	Unit
1.13	Work	person/vehicle
2.76	Other	person/vehicle
Source: Mobilität in Deutschland (2008)		

In trip assignment stage, trips were modeled in the form outbound-return trip, not as one-way trip. Demand matrices of HW and HO with certain modes will be doubled in the form of outbound-return trip. It is worth stressing that the return trip of HA was not added in the form of return trip because not every trip to airport would return back in the same day. After the assignment task, the updated impedance are then fed back to mode choice in a loop iteration process. Figure 6.8 illustrates the simplified flowchart of assignment task.

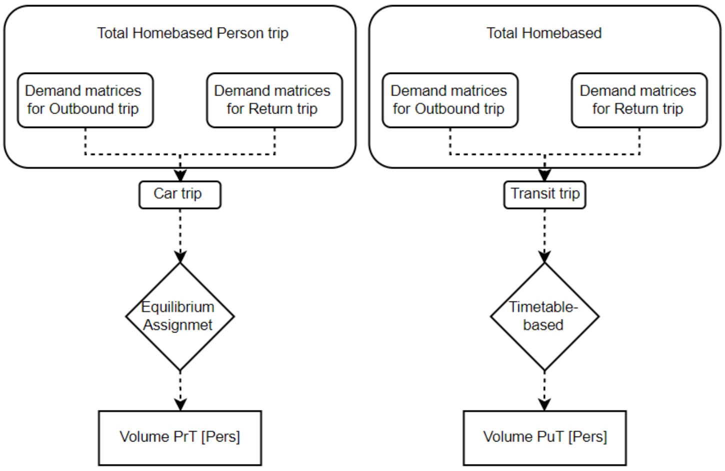

Figure 6.8: Simplified flowchart of route assignment model in VISUM

6.3.7 Simulation result

The assignment analysis yielded a plausible result with respects to private (PrT), but not public transport (PuT). Figure 6.9 shows the volume of PrT on network. In contrast, pubic transport assignment appears to misjudge the situation. An example of it is the unexpected high demand is distributed into the the link operated by regional bus even though shortest path algorithm indicated S-Bahn S1 is the shortest. The incidence error can be found in Figure 6.10. Figure 6.11 shows both private and public transport on the network. For convenient visualization, a maximum threshold of volume [Pers] has been set to both volume of PrT and PuT respectively. A threshold value and scale dimension are mentioned with all figures.

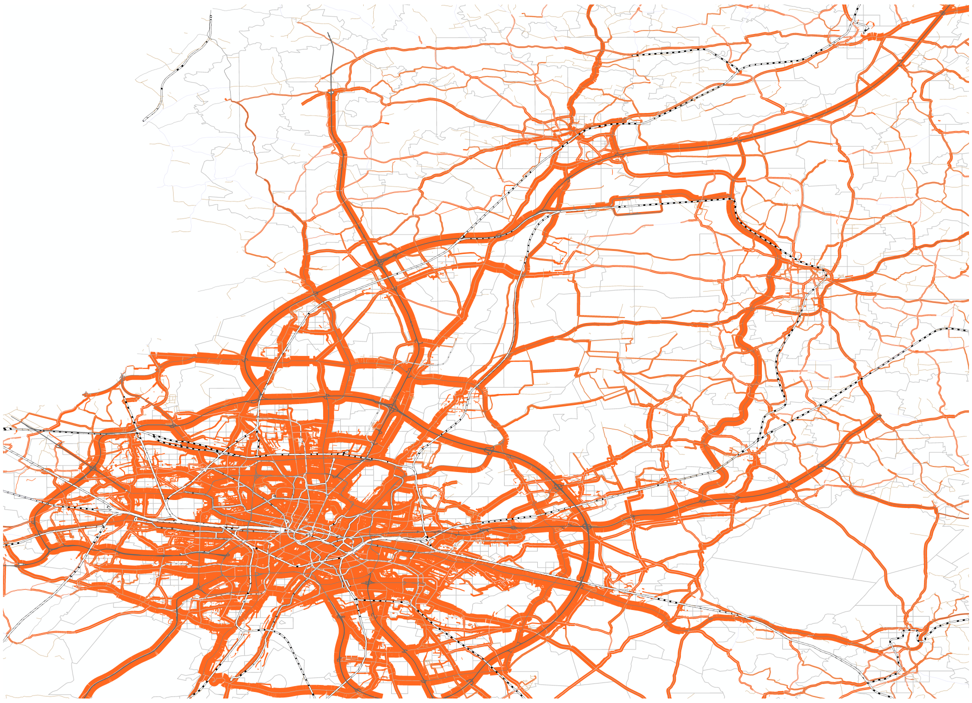

Figure 6.9: An example of PrT assignment result in VISUM - Threshold of 5,000 Pers trip with scale dimension 2

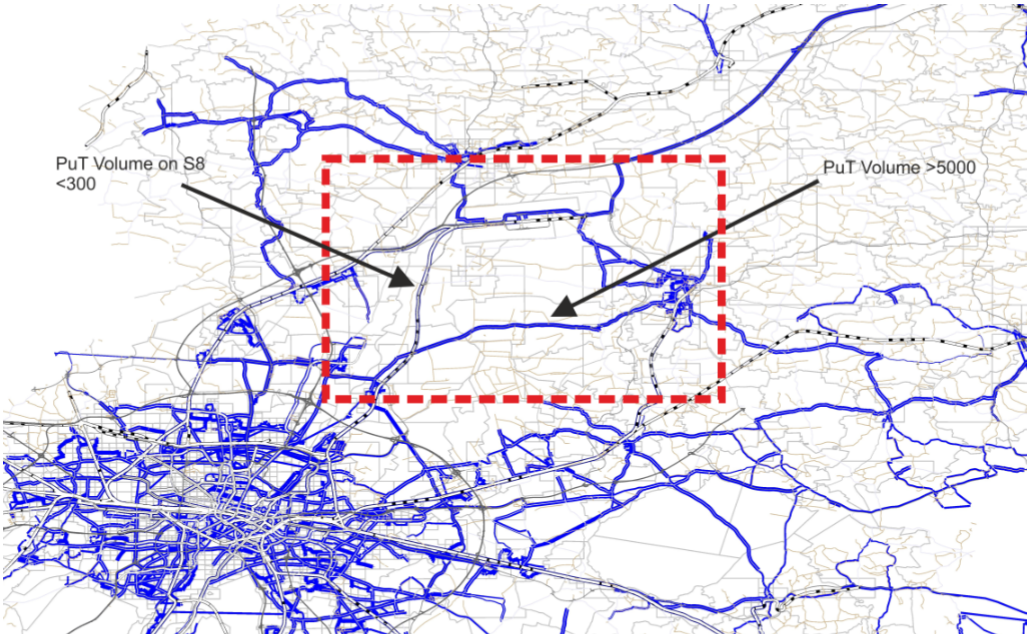

Figure 6.10: An example of PuT assignment result in VISUM - Threshold of 5,000 Pers trip with scale dimension 2

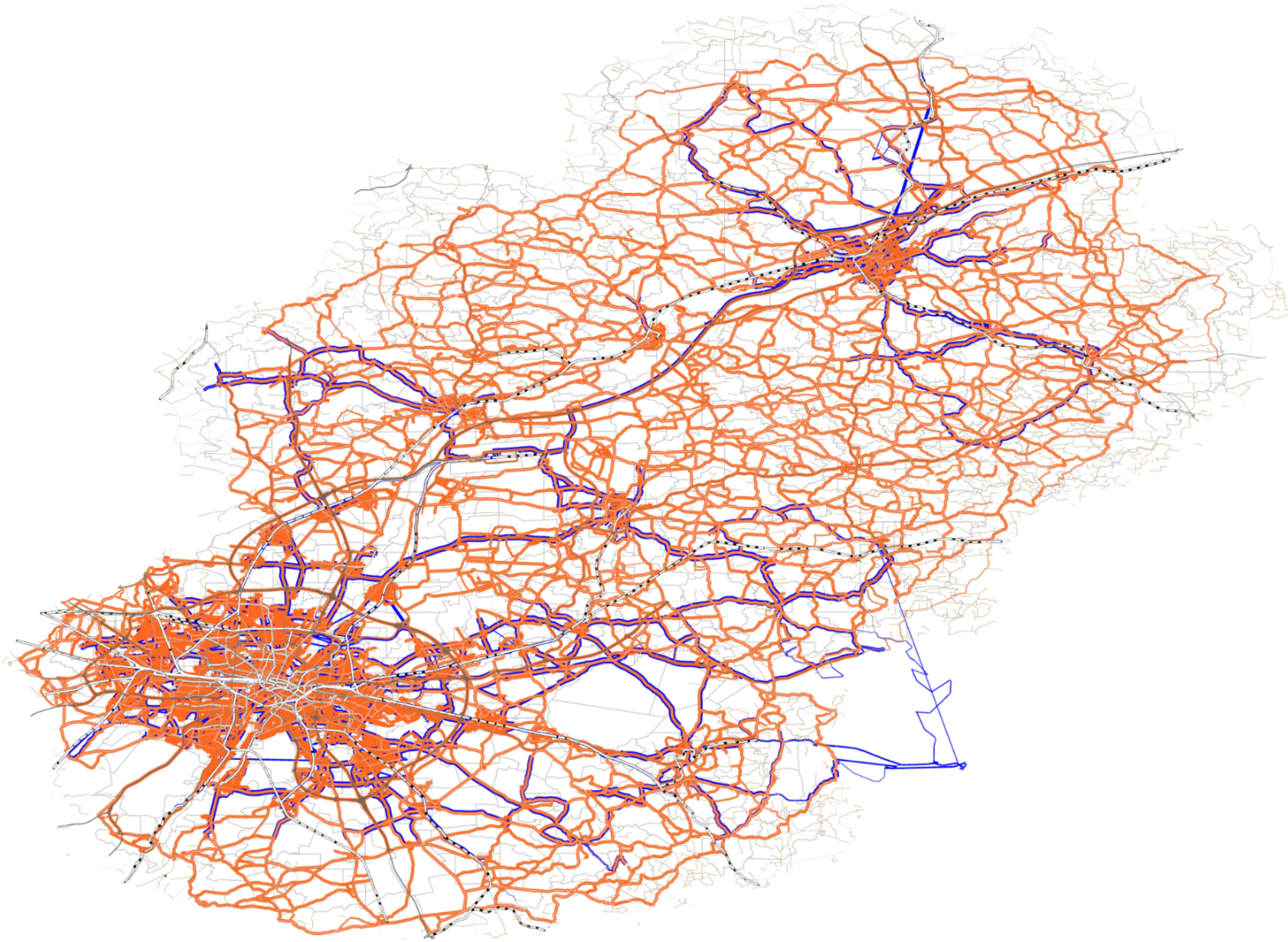

Figure 6.11: Assignment results in base scenario - Threshold of 500 Pers Trip with scale dimension 1.5
Source: Own illustration with VISUM

6.3.8 Attempted solutions

In attempt to solve the modeling issues, different variations of model were applied. One of the applied solution was to re-design timetable of all line routes to airport without coordination. The simulation results did improve the public transport assignment but still high distribution of demand on links with regional buses. Even the new connection through Erding is shorter in both travel time and distance compared to bus. Other solution applied to improve the model was to re-run the simulation 20 times so that the model could find the shortest path. The results after multiple simulation appears to show slight improvement. Other than above two solutions, using shortest path approach in public transport assignment was attempted. However, this simulation took roughly 10 hours for 2,796 OD pair. This approach may be deemed as inconvenient due to its extremely time consuming. The result also did not improve very much.

As described in Section 4.2, the input data is not complete. Many system assumptions were applied for convenient use. Data was only verified through computational software (i.e., Feed Validator), and the verification was not sufficient enough to ensure the accuracy of the data. It is possible the miscalculation of public transport assignment can be fixed by a finer dataset. Also, expert assessment can allow a better evaluation of public transport assignment. As the assignment results cannot be used, only mode choice model was applied for further discussion.

Chapter 7

Scenario Analysis

The objective of this thesis is to assess the impact of the Erding Ring Closure on passenger flows in Munich Region. For this assessment, a mode choice and route choice model were built to realize the the project's impact on travel demand. The model built was then applied to the scenario with Erding Ring Closure infrastructure. Three scenarios in total will be discussed in this chapter. The results of the analysis of each scenario are described in this chapter.

In Chapter 1, a brief account of the proposed Erding Ring Closure is presented. As stated, the project is planned to close the S-Bahn loop for airport access. Also, it is intended to improve the connection of trans-regional service from Landshut to Mühldorf. Erding Ring Closure project comprises of Erding Ring Closure, Neufahrn Curve, and Walpertskirchen Link. However, Walpertskirchen Link is not considered in this study since it is still in design process, and no concrete information of it is available.

7.1 Public transport network

The proposed rail infrastructure for scenario is incorporated into the public transport network by an allocation of new nodes and links with its respective characteristics. The development scenarios have the following characteristics: a mainline rail type, operational speed of 80 kilometers per hour, 2 tracks, and a stop point. The proposed private transport network is described in Figure 7.1. For the impact study, the a couple of system assumptions have been applied. Table 7.1 summarizes the new transit service and modified service for all scenarios. The following services run in both directions though the table indicates only one way route.

Table 7.1: Summary of new transit service for all scenario

Line ID	**Type**	**Line Routes**	**N. vehicle journeys**	**Headway (Peak hour)**	**Normal Headway**
S2	Extension	Airport-Peterhausen	55	20 min	20 min
SEF	New	Fresing- Erding	45	15 min	30 min
FEX[1]	New	Landshut- Dorfen	20	60 min	60 min
ÜFEX	New	Landshut- Dorfen	20	60 min	60 min

[1] FEX operates with more intermediate stops

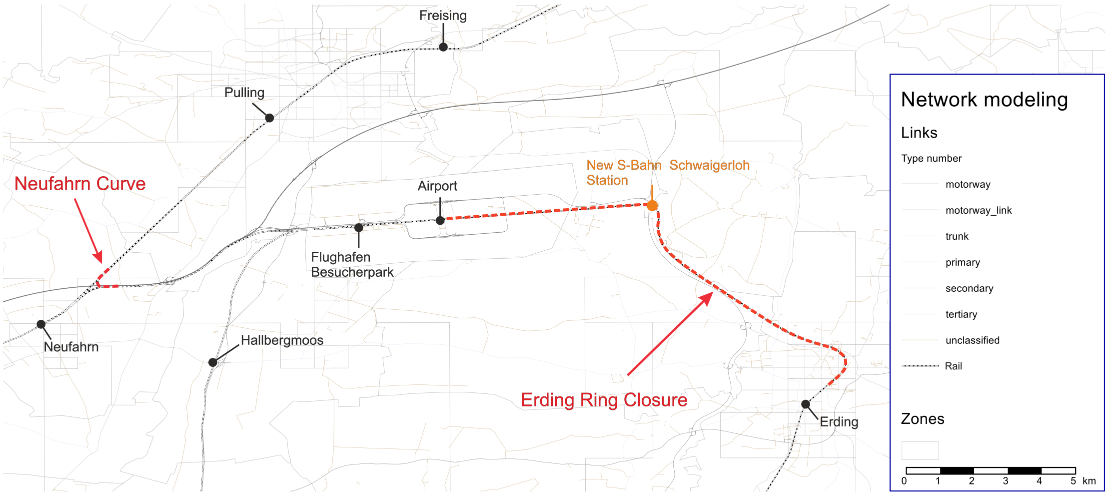

Figure 7.1: Erding Ring Closure Scenario
Source: Own illustration with VISUM

7.2 Prediction

The proposed rail connection and transit services described in Section 7.1 was used to estimate the impact of Erding Ring Closure. This section discusses all future scenarios and the prediction results. To explore the impact of Erding Ring Closure, scenario with Ering Ring Closure line added is analyzed. Other two scenarios are created in addition to scenario Erding Ring Closure in order to test model sensitivity. The specifications for these two scenarios are doubled auto operating cost (AOC) and doubled parking cost (PC). It is worth noting that the scenario doubled AOC and scenario doubled PC are modeled based on the situation after Erding Ring Closure and Neufarhn Curve are put into operation. As discussed in chapter 6, all observed attributes were related to transport facilities. The model described in previous chapter is applied to predict the impact. Furthermore, as described in Section 6.3.7 and Section 6.3.8, public transport assignment results are unrealistic to the point that cannot be applied to analyze the impact of Erding Ring Closure. Thus, it was decided not to make a comparison study of both private and public transport assignment.

7.3 Scenario Erding Ring Closure

Key aspects being discussed in this section are categorized into three cases - air passenger mode share (HA), airport mode share (HA-HO-HW), and overall mode share in study area. To compare the results, four zones adjacent with airport were assumed to be airport zone (previously discussed in Section 5.4). Figure 7.2, Figure 7.3, and Figure 7.4 present the results predicted by model compared to scenario Erding Ring Closure according to its designated case. Keep it in mind, HA represents only air passenger trips, not the commuting trip to airport. The commuting trip to airport is covered by trip purpose - HW.

Air passenger mode share (HA)

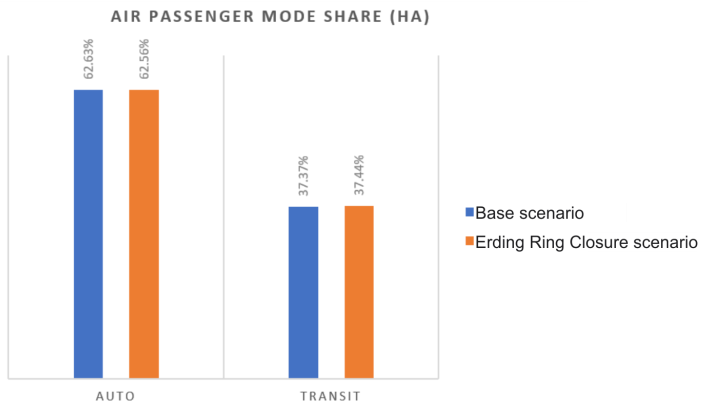

Figure 7.2: Air passenger mode share - Comparison between base scenario and Erding Ring Closure Scenario

The effect of Erding Ring Closure on travel mode share has been minimal, but somewhat encouraging. With the improvement of the airport access through Erding, transit is able to attract trips from the dominant auto mode. The analysis results presented in Figure 7.2 shows the mean difference of pre- and post- Erding Ring Closure. The predicted value appears to be minutest for both modes. For instance, there is a 0.07% decrease for auto in scenario Erding Ring Closure. This very small change can be referenced to the travel time. It is true that airport will have three rapid transit connections; however, the new service does not have any impacts on the daily mobility. This is due to the longer travel time with the new service. Despite the existence of new service, travel to airport with S8 still remains superior. Travel time on new service predicted by the model is 54 min from Hauptbahnhof to airport S-Bahn station. Moreover, travel time will be 34 min to reach airport if trip starts at Ostbahnhof. In contrast, travel time with S8 only takes 30 min and 41 min from Ostbahnhof and Hauptbahnhof respectively.

Mode share to airport (HA-HO-HW)

Regardless of trip purposes, Figure 7.3 focuses on the trip with airport as destination. The predicted shares are as follows.

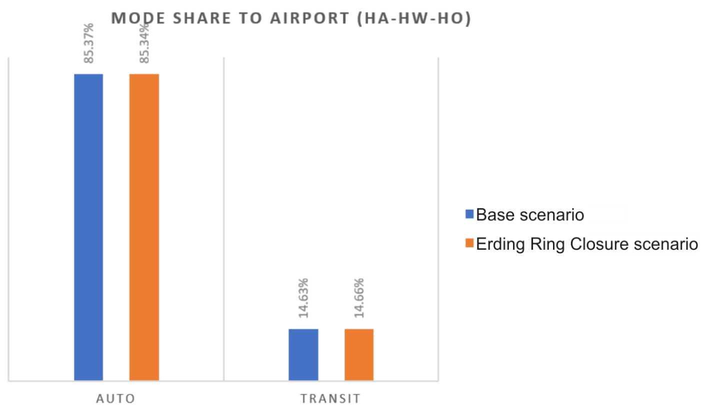

Figure 7.3: Mode share to airport - Comparison between base scenario and Erding Ring Closure Scenario

Similar to air passenger mode share, the new service does not show much impact on the mode share.

Overall mode share in study area

Figure 7.2 indicates mean mode share in study area predicted by model compared to base scenario. The results of predicted shares are as follows.

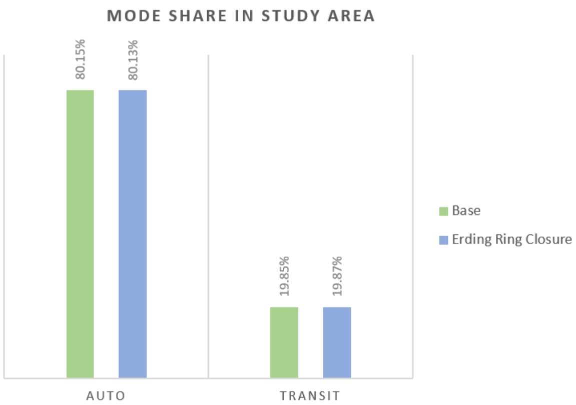

Figure 7.4: Mode share in study area - Comparison between base scenario and Erding Ring Closure Scenario

Aside from the other two cases, the new rail corridor increase transit share by only a slight amount from 19.85% to 19.87% in the case of study area. The slightly better transit share may be due to better transit service, but not enough to draw a larger amount of share from auto.

7.4 Scenario double AOC

The reason to include this scenario in this thesis is mainly to test the model sensitivity. Other reason for it is the travel cost has been found to have a large influence on mode choice (Ortúzar 2000; Vuchic 2005; Ahern & Tapley 2008; Twaddle, 2011). These results suggest that increasing in auto operating cost can significantly affect the decision of individual on mode choice.

Air passenger mode share (HA)

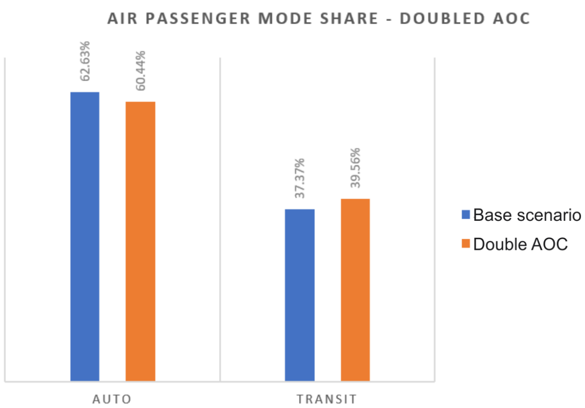

Figure 7.5: Air passenger mode share - Comparison between base scenario and Doubled AOC

This scenario proved to be effective if we want to push car users from their personal automobile. This result reflect the push-pull measure that aims to encourage traveler to use a more sustainable transport besides auto. According to Figure 7.5, auto saw a large reduction from 62.63% to 60.44%. This results also highlight the importance of cost variable in mode share analysis.

Mode share to airport (HA-HO-HW)

Regardless of trip purposes, Figure 7.6 focuses on trip with airport as destination. As expected, there is a significant shift from auto to transit when high auto operating cost is considered. The predicted shares are as follows.

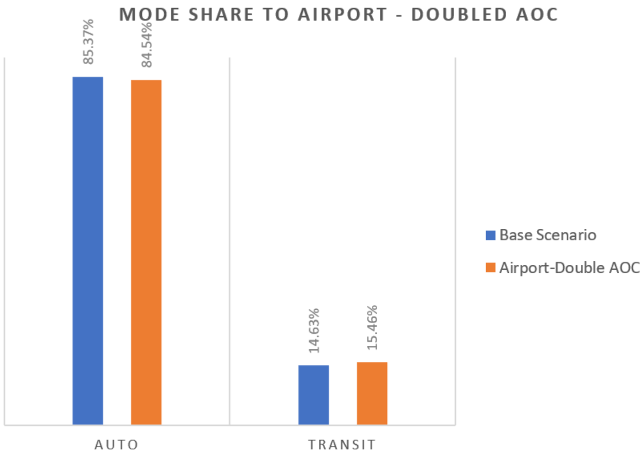

Figure 7.6: Mode share to airport - Comparison between base scenario and Doubled AOC

Overall mode share in study area

Figure 7.2 indicates mean mode share predicted by model compared to base scenario. The results of predicted shares are as follows.

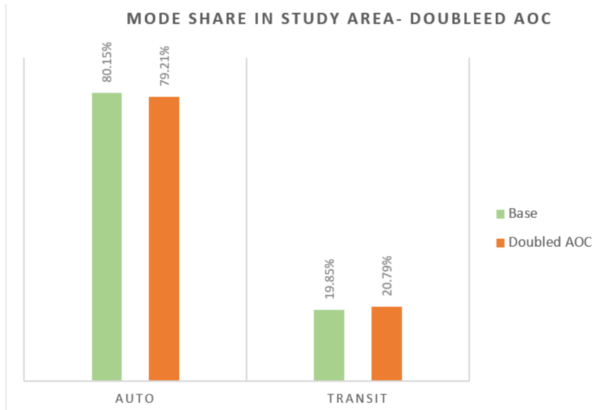

Figure 7.7: Mode share in study area - Comparison between base scenario and Doubled AOC

In contrast, the overall mode share does change but with a slight amount. However, the result is statistically significant.

7.5 Scenario double Parking Cost

The decision to include this attribute is because this variable is so responsive to policy change. The scenario with doubled parking cost only applied to commuting and other trip, not the airport trip. It may be not rational to double the airport parking fee as its parking places are designed to accommodate thousands of cars. General parking in city center is different as it is always high in demanded. Thus, increasing parking cost in general parking cost is more reasonable than airport parking.

Mode share to airport (HA-HO-HW)

Regardless of trip purposes, Figure 7.2 focuses on trip with airport as destination. The predicted shares are as follows.

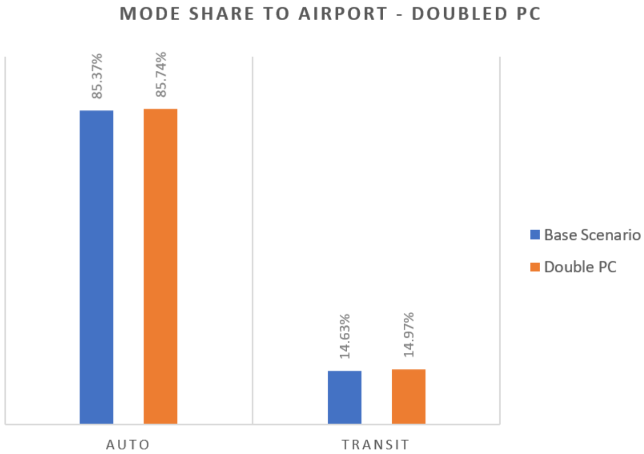

Figure 7.8: Mode share to airport - Comparison between base scenario and Doubled PC

As expected, the results can be in turn explained by the burdensome of high operating cost. With auto becomes more expensive to use, traveler may consider using transit. This is evident by the results predicted. There is an obvious rise in transit when parking cost is doubled.

Overall mode share in study area

Figure 7.2 indicates mean mode share predicted by model compared to base scenario. The results of predicted shares are as follows.

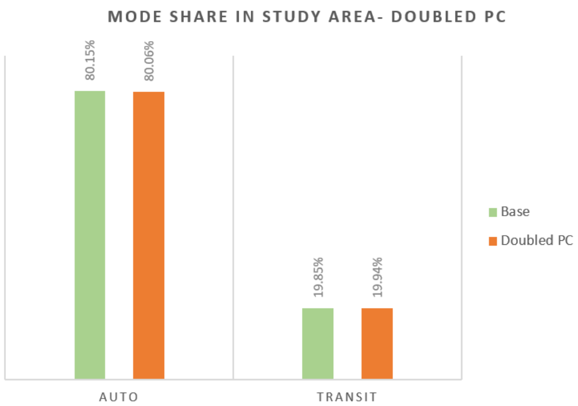

Figure 7.9: Mode share in study area - Comparison between base scenario and Doubled PC

The analysis results shows that increasing in parking cost does not have impact as large as increasing in auto operating cost. Although the shift in mode share appears to be small in value, at least, this policy change can push a few travelers to use transit.

7.6 Summary

The predicted share for base case scenario are indeed different from the mode share provided by MiD. The share in this chapter are predicted as a mean value without taking the trip purpose into account. Further, it is also worth noting that only attributes relative transport system (time and cost components) are considered. As one would expect, auto shares are predicted to have the larger share compared to transit. Auto share still outperforms the transit though transit becomes more attractive. This is perhaps because of the high level of comfort, convenience, and flexibility of auto. Table 7.2 summarizes only the predicted share in study area regardless of trip purpose. The results are based on Figure 7.4, Figure 7.7, and Figure 7.9.

Table 7.2: Mode share for trips in Munich region by scenario

Mode	**Base/%**	**ERC/%**	**Doubled AOC/%**	**Doubled PC**
Auto	80.15%	80.13%%	79.21%	80.06%
Transit	19.85%	19.87%%	20.79%	19.94%

Chapter 8

Conclusion

This thesis aims to assess the impact of Erding Ring Closure on passenger flows in Munich region. The study focused only on two alternatives - auto and transit as these two are deemed the most suitable for regional scale study. To help select models, literature and previous studies relevant to this topic was studied. Consequently, binary logit choice model based on discrete choice theory was built and applied to scenarios to predict the changes in modal split. Apart from mode choice exercise, an attempt to find out whether an addition of new infrastructure and service can affect the present pattern of route choice was made. The study analyzed assignment of mode-specific trips on network by using equilibrium assignment for private car and timetable-based approach for public transport. Furthermore, this thesis used the computational software to aid the analysis process because of its ability to model the travel demand as realistic as possible and time-saving. PTV VISUM, a macroscopic traffic simulation software, was employed to model the mode choice and simulate route assignment.

The attributes used to specify the mode choice model was limited to only the objective variables that fall under the category of transport facility. While estimating the model parameters is not a simple task in the case of limited data availability, the study adopted derived parameters from other study to formulate mode choice. The coefficients presented in the analysis have proved to be viable for the study. As expected, the analysis with derived parameters yielded a reasonable result for airport trip, which is by definition a long-distance travel trip. On the other hand, the coefficients, however, seemed not to be feasible with short-distance travel trip - commuting and other trip. Despite these results, mode-specific constants still needed to be calibrated to reflect the actual mode share of all trip purposes. Model accuracy test was undertaken to match the actual mode share reported by MiD and of airport. The calibration indicated desirable small constants for transit in all trip purposes.

To find out if Erding Ring Closure has an impact on travel mode, three scenarios were performed. The results of scenarios with Erding Ring Closure presented the minimal impact of the new service on modal split. The impact has not been wide as expected; however, the impact was encouraging and sobering. The addition of new connection was able to draw passenger from auto. Nevertheless in overall, auto still dominated the mode share regardless of trip purposes. Another two scenarios attempted to analyze the impact of high auto operating cost and high parking cost. These two scenarios were modeled with the existence of Erding Ring Closure. Scenario with high auto operating cost highlighted significant decrease in auto use compared to base scenario. More importantly, double operating cost has led to remarkable reduction in auto share to airport. This signifies the importance of operating cost variable compared to travel time. The last scenario, whose parking fee is assumed to be doubled, did not add much competition to auto. The resulting model seems to explain that increasing in parking cost has less impact than increasing auto operating cost.

Another topic addressed in this thesis is the analysis of route assignment. For the analysis of route choice, only base scenario was attempted. Through user equilibrium, results revealed a fair distribution of passenger volume on the link. On the transit side, the assignment of public transport made use of timetable-based approach to assign the trips on the routes. Unfortunately, the analysis did not yielded neither accurate nor plausible results of public transport assignment. Assignment result exhibited unrealistic situation for base scenario. For this reason, thorough scenario analysis was not able to perform for public transport. As one would expect, Erding Ring Closure aims to provide a better alternative to transit, not auto. A discussion on private assignment would be not much of interest.

8.1 Concluding remark

This thesis has partially achieved the objective that was set. The results from the analysis are statistically significant though they are minimal. Each scenario encompasses three different aims, but all endeavor to forecast the potential impact as a result of new infrastructure, new service, and policy changes. Scenario with Erding Ring Closure highlights the importance of time variable. Though the connection to airport has been improved, auto outperforms the transit. The other two scenario attempt to investigate any impact in response to policy change. The results are evident by a decrease in auto share regardless of trip purposes. Additionally, the results presented in the last two scenarios appear to contradict some previous studies' claim (Moeckel et al., 2015), which stated that parking cost was perceived as more onerous than auto operating cost. Last but importantly, the overall results evidently indicate that airport trip is susceptible to the influence of Erding Ring Closure.

Besides, the study emphasizes the importance of input dataset. The results derived from the analysis are dependent on the level of accuracy of the dataset. The miscalculation in public transport assignment stage could be explained by the poor timetable information. Timetable-based approach relies on a precise departure and arrival time of public transport. With reliable timetable, this approach takes into account of a coordination in order to yield a very precise result. However, the loose timetable information has misled the assignment, and thus makes it misjudge the situations. Moreover, the current dataset is not complete, and this requires a significant improvement of dataset. This error in dataset can be amended through expert assessment and more experiment tests.

The use of computational software for in-dept analysis has proved to be effective and efficient. VISUM makes many contribution to the analysis process. VISUM's ability to model realistic travel demand is evident and proved. The results are also feasible and logical according to input data used.

Overall, I argue that this work is novel and this study requires further researches to help improve the validity and accuracy of the results.

8.2 Limitations of the study

There are several limitations that should be addressed to make ways for future work to improve the reliability and validity of predicted results. Some of the limitations are described as follow.

Modeling a large scale truthful travel demand is not a simple task. The model requires a significant amount of input data, which must be as accurate as possible. The input data used to build model in VISUM are entirely made from assumptions. GTFS was created from scratch, applying many assumptions that do not reflect the reality, mainly for bus, regional bus, and regional train. This has resulted in inaccurate timetable and poor route information for public transport. Should GTFS be utilized for future research, a correcting work in source dataset is required.

Another limitation of the model is the adjustment of mode-specific constants with MiD data. Mode-specific constants for home-based work and home-based other trip were calibrated to match the MiD mode choice pattern which is the actual share from all urban areas in Germany. Performing the calibration with information exclusive to the study area would have provide a better and more accurate result.

Constrained by the lack of data available, the study did not cover the non-home-based (NHB) trip. NHB trip normally accounts for roughly 25% to 30% of daily mobility by individuals in urban areas (Schultz & Allen, 1996). Extending the study with NHB trip could not only contribute to better urban travel model but could also increase the sensitivity and accuracy of the forecast.

Setting in a future time frame, travel demand of today may not be deemed convenient to describe the future travel demand with Erding Ring Closure. One favored solution of it can be achieved through the application of expansion factor or the use of demand growth rate that is derived from empirical analysis.

Last but importantly, model was not calibrated and validated before it was applied to scenarios. Thus, it is difficult to determine the validity of the results.

8.3 Suggestion for future researches

The models described in this study has been proved to be suitable with mode share analysis, however, not for route assignment task. The model failed to yield thorough and plausible results for public transport assignment. Hence, this study could be a good starting point for future work to better understand the causes of the incidences. Future researches are recommended to help improve this study by addressing the limitations mentioned above.

Moreover, in this study, the variable included in mode choice model only address the attributes of transport facility. It would be interesting, if future works can also extend their focuses to other explanatory variables such as individual related attributes and trip characteristic. This can perhaps predict more precise results.

Furthermore, the study used equilibrium assignment to assign person car trips on the network. Performing the assignment with a more sophisticated approach like Stochastic Equilibrium could also explain a realistic situation of passenger flows.

A detailed discussion on travel time and relative accessibility to Messe München is recommended. The research on these two aspects may help realize the impact of Erding Ring Closure.

Additionally, the study geographically distributed the passenger survey to the level of resolution of TAZ. Passenger survey only reflects the distribution at the time of the survey and may not reflect the future demand. The use of passenger survey data as distribution model may not provide a suitable level of resolution of air passenger trip origins. It would be interesting if airport trip generation is modeled instead of exogenously incorporating passenger survey data into the demand model. Previous studies on airport trip generation have been conducted by California High-Speed Rail system (CSI et al., 2006), Gosling et al. (2003), and Gosling (2011).

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Appendix A

Mode choice modelling for long-distance travel conducted by Moeckel, Fussel, and Donnelly (2015)

Derived parameters used for the mode choice model

Table 1 Coefficients and variables for utilities of drive-alone and shared-ride modes

Coefficient	Description	Value
$u_{i,j,m,p}$	Utility of mode *m* (drive-alone, shared-ride 2, shared-ride 3, or shared-ride 4+) from zone *i* to zone *j* for purpose *p*	
ivtc	In-vehicle time coefficient: parameter evaluating the travel time spend in the vehicle	(b) −0·026, (p) −0·018, and (c) −0·025*
$tt_{i,j}$	Travel time from zone *i* to zone *j* by auto	
ovtc	Out-of-vehicle time coefficient: parameter evaluating the travel time spend out of the vehicle	(b) −0·052, (p) −0·036, and (c) −0·050*
autoEgr	Auto-egress time: time spent to walk from the parking location to the final destination	5 min
$prkc_p$	Parking costs coefficient by purpose *p*	(b) −0·006, (p) −0·012, and (c) −0·010*
p_j	Parking costs in zone *j*	
occ_m	Number of persons traveling by drive-alone, shared-ride 2, shared-ride 3, and shared-ride 4+	1, 2, 3, 4·1 persons
$aocc_p$	Auto operating costs coefficient by purpose	(b) −0·004, (p) −0·008, and (c) −0·007*
$dist_{i,j}$	Distance from zone *i* to zone *j* in miles	
aoc	Auto operating costs	0·0874 cents $mile^{-1}$

*Trip purposes: (b) business, (p) personal, and (c) commute; in line with nested mode choice theory, parameters are scaled by the nesting coefficient.

Table 2 Coefficients and variables for utilities of transit modes bus, rail, and air

Coefficient	Description	Value
$u_{i,j,m,p}$	Utility of mode *m* (bus, rail, or air) from zone *i* to zone *j* for purpose *p*	
ivtc	In-vehicle time coefficient: parameter evaluating the travel time spend in a vehicle	(b) −0·026, (p) −0·018, and (c) −0·025*
$tt_{i,j,m}$	Travel time from zone *i* to zone *j* on mode *m*	
ovtc	Out-of-vehicle time coefficient: parameter evaluating the travel time spend out of the vehicle	(b) −0·052, (p) −0·036, and (c) −0·050*
$trnAcc_m$	Time to access the transit, which includes the walk from the vehicle to the transit platform or gate, time for check-in and time for security checks	Bus: 15; rail: 30; and air: 60
ntrc	Coefficient on number of transit transfers	−0·01*
$trnsf_{iStat,jStat,m}$	Number of transfers to travel from iStat to jStat on mode *m*	
$trfc_p$	Transit fare coefficient by purpose	(b) −0·006, (p) −0·012, and (c) −0·010*
$fare_{iStat,jStat,m}$	Transit fare from iStat to jStat on mode *m*	
$tfqc_p$	Coefficient on frequency of service per day by mode	(b) 6, (p) 2, and (c) 3*
$frqu_{iStat,jStat,m}$	Frequency of service from iStat to jStat on mode *m* per day	
$dist_{i,j}$	Distance from zone *i* to zone *j*	
$trnEgr_m$	Time to egress the transit, which includes the walk from the transit platform or gate to a vehicle and time for collecting baggage	Bus: 10; rail: 15; and air: 20

*Trip purposes: (b) business, (p) personal, and (c) commute; in line with nested mode choice theory, parameters are scaled by the nesting coefficient.

Table 4 Comparison of parameters across long-distance logit-based mode choice models

Author	Grayson (1981)			Wen, Koppelman (2001)[1]	Bhat (1995)[2]	Baik *et al.* (2008)		Ridout, Miller (1982)	Wilson *et al.* (1990)
Purpose	Business	Social	Entertainment		Business	Business	Non-business		
Sample size	2720 (NTS 1977)			4324	2769	540000 (ATS 1995)			1624
Cost	−0·0328	−0·0111	−0·0111	−0·0173	−0·0318	−0·0309 to −0·0094	−0·0275 to −0·0191[3]		
Auto-operating costs									
Fare/income								−0·3507	
Travel cost/distance									−15·084
In-vehicle time	−0·02	−0·238	−0·0079	−0·0031	−0·011	−0·0269 to −0·2608	−0·1219 to −0·2444[3]	−0·1075 to −0·04029[4]	
In-vehicle time for rail and air									
In-vehicle time for bus and auto									
In-vehicle time for auto									
In-vehicle time for rail									
In-vehicle time for air									
Travel time/distance									−166·285
Out-of-vehicel time, wait	−0·0244	−0·009	−0·003	−0·011	−0·0362				
Frequency				0·0288	0·0741				0·018
Frequency / distance									
Transfers									
Frequency for rail and bus									
Frequency for air									
Access	−0·0006	−0·0016	−0·0015					−0·01442	
Access for rail and bus									
Access for air									
Egress air								0·0621	
Egress rail								−0·004578	
Egress bus								−0·03612	
Constant auto	0	0	0	5·133	0				
Constant transit									
Constant bus	−3·159	−3·016	−1·797	0	N/A				16·596
Constant rail	−2·461	−2·828	−3·288	4·981	−0·1763			0·2032	18·016
Constant high-speed rail									
Constant air	−1·313	−3·166	−3·435	6·264	−0·4883			−0·3391	15·382
Constant large city train					1·9066				
Constant large city air					0·7877				
Constant Income train					−0·0167				
Constant income air					0·0223				
Constant manufacturing employment								0·8612	
Constant finance and service employment								0·2715	
Constant medical & governmment employment								0·6755	

Table 4 Extended

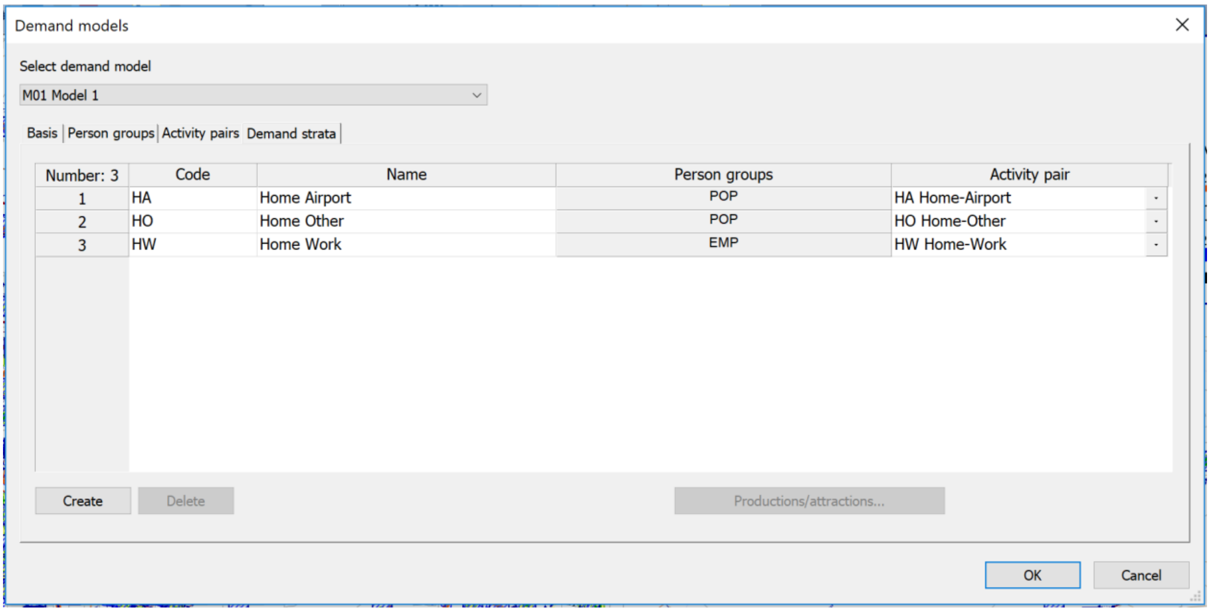
Koppelman, Wen (2000)[5]	Mandel *et al.* (1997)	Yao, Morikawa (2005)		Bhat (1997)	Holguín-Veras *et al.* (2003)	R^{3}Logit			
		Business	Non-business	Business	Business	Business	Personal	Commute	Eval.
		18798	32202	3593	1,656				
−0·0242	−0·62 to −0·04[4]	−3·326[7]	−2·2442[7]	−0·1728 to −0·0166	−0·028119 to −0·006787	−0·006	−0·012	−0·010	√
						−0·004	−0·008	−0·007	only R3L
−0·0076	−1·69 to −0·14[4]			−0·003 to −0·657		−0·026	−0·018	−0·025	√
		−2·136	−0·562						
		−2·06	−0·562						
					−0·015174 to −0·003951				
					−0·010983 to −0·002527				
					−0·643502 to −0·009693				
−0·0321				−0·1627 to −0·0239	−0·014219 to −0·011175	−0·052	−0·036	−0·05	high
0·0651	−0·10 to 0·08[6]			0·1615 to 0·5784					
						6	2	3	only R3L
						−0·1	−0·1	−0·1	only R3L
		0·248	0·164						
		0·489	0·164						
					−0·015805 to 0·031467				
		−1·65	−0·519						
		−1·65	−1·15						
0		−5·17	−0·603	0	2·4213 to 2·66552	−0·08 to 0·11[8]	0·46 to 0·58[8]	−0·51 to −0·20[8]	√
						2·24	0·52	0·30	only R3L
N/A		−11·3	−2·27			0	0	0	√
1·2942		0	0	−3·0617 to 4·7763		−2·39	−1·47	−0·62	√
		0·45	0·587						
1·9603		−1·28	1·887	−1·3691 to 4·3404	3·30624 to 85·00947	0·88	1·21	1·53	√
				−0·084 to 1·9273					
				−1·3691 to 2·6892					

[1]Parameters of GNL Model 2, With train-car-air nest
[2]Parameters of Heteroskedastic Extreme Value Model
[3]Distinguished by five income groups
[4]Distinguished by mode (Air, Rail and Bus)
[5]PCL Model, Train-car and air-car similarity
[6]Distinguished by mode (Air and Rail)
[7]In 10000 Japanese Yen
[8]Distinguished by auto occupancy

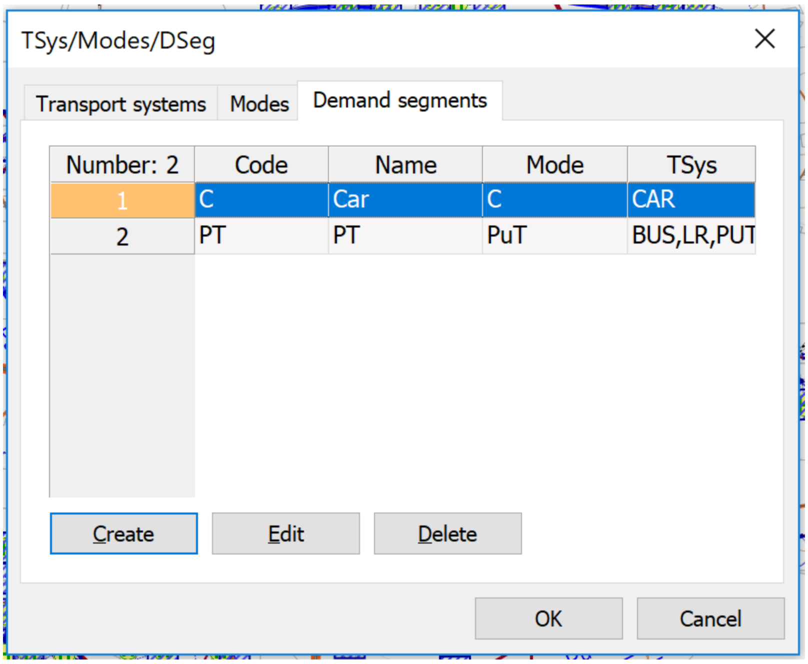
Appendix B

Network modeling in VISUM

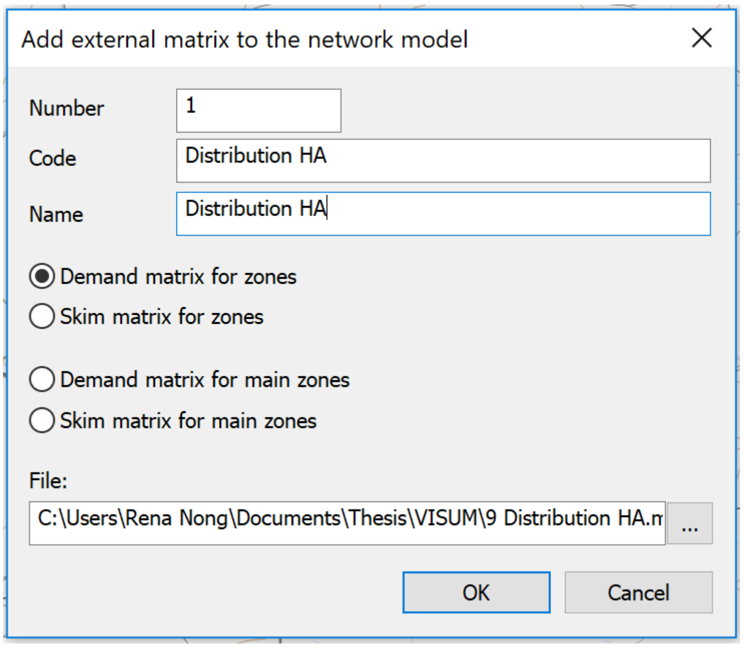
Task 1: Demand Model



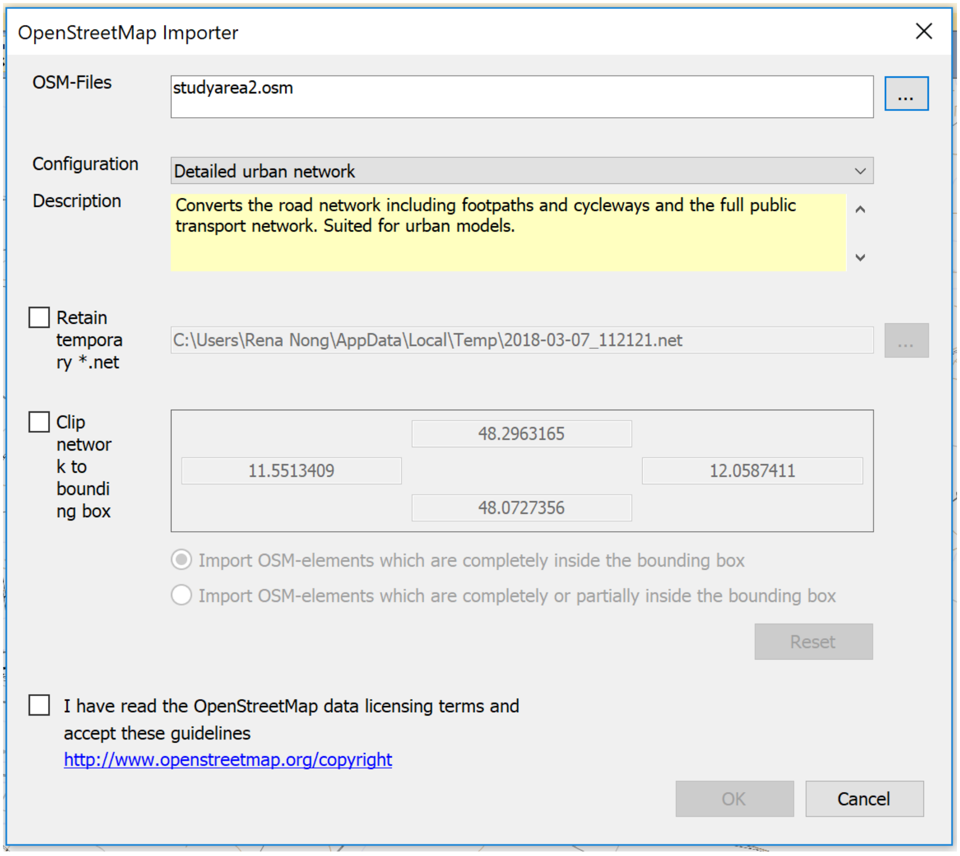
Task 2: Transport System Modes



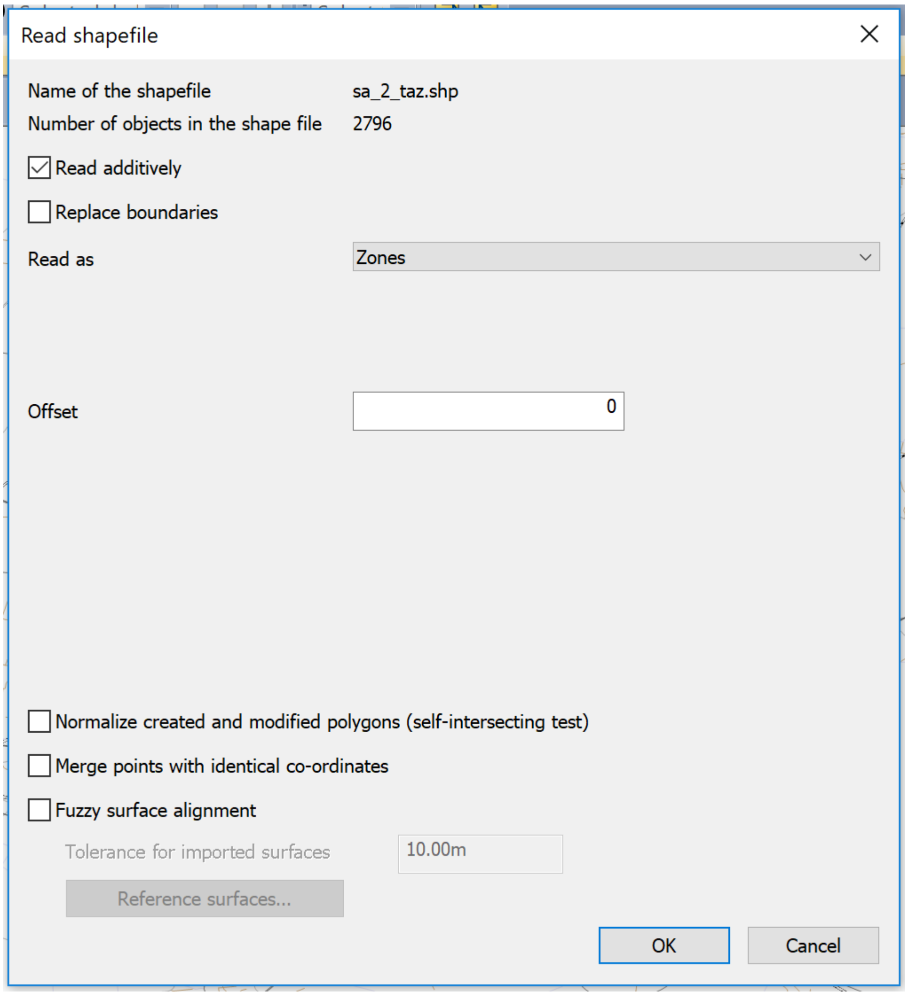
Task 3: Importing Matrices



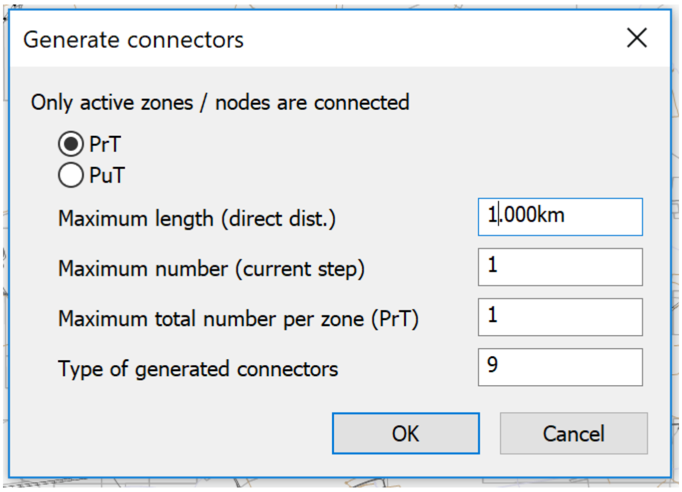
Task 4: Importing OSM Data



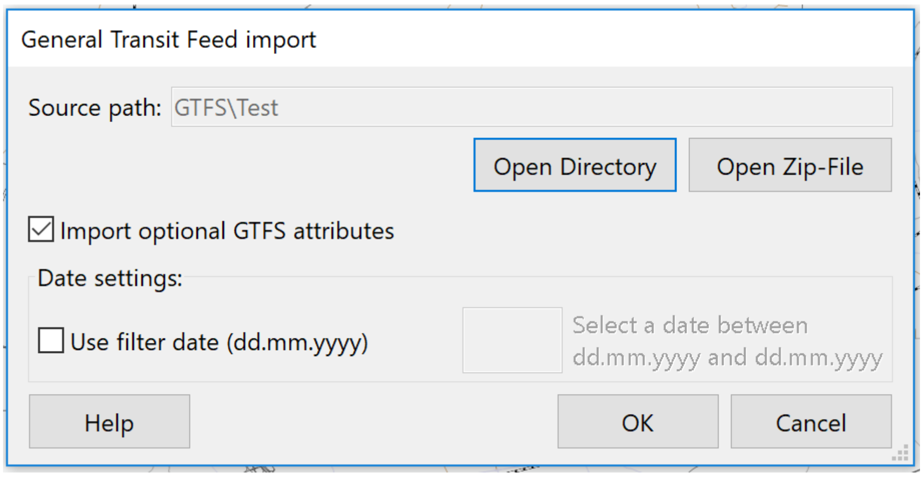
Task 5: Importing Zone



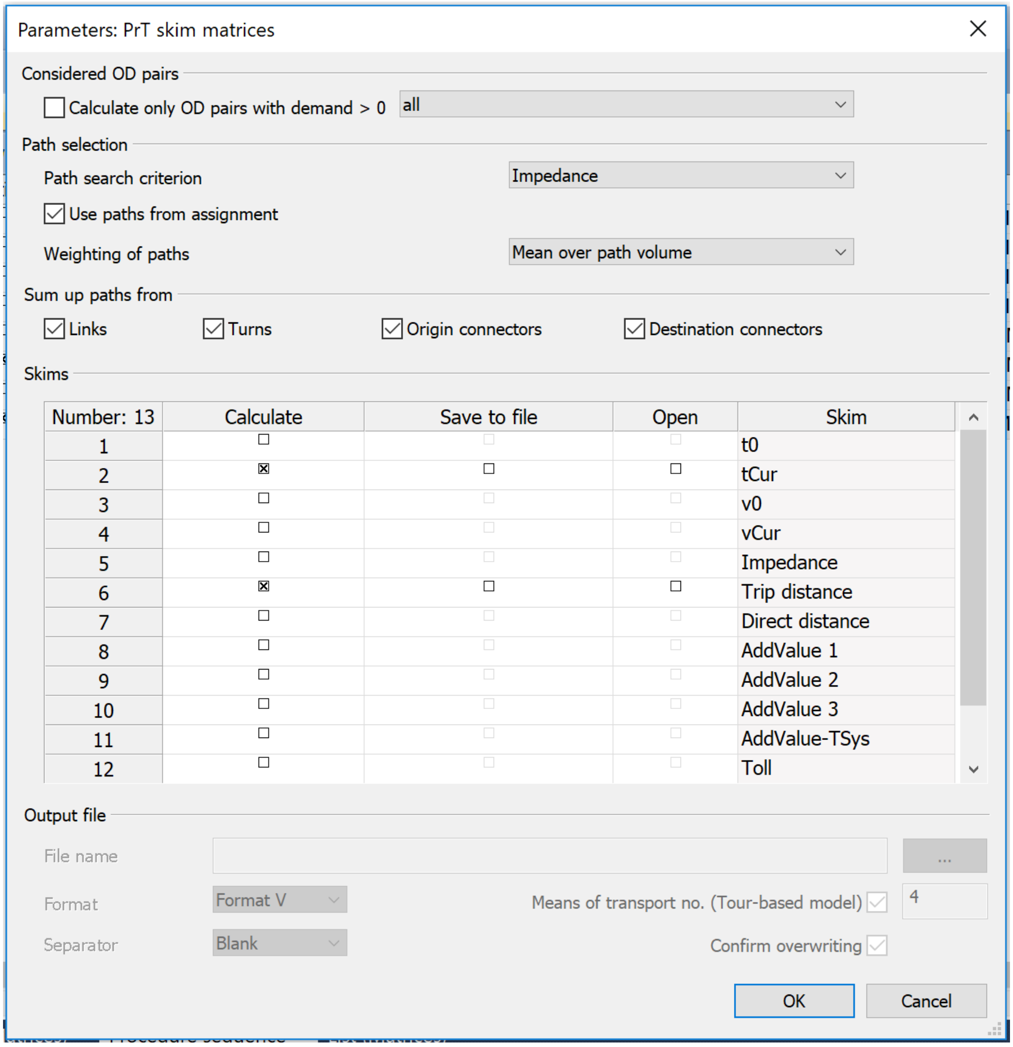
Task 6: Setting Connector (Example of PrT Connector) - 5 km is set for direct distance



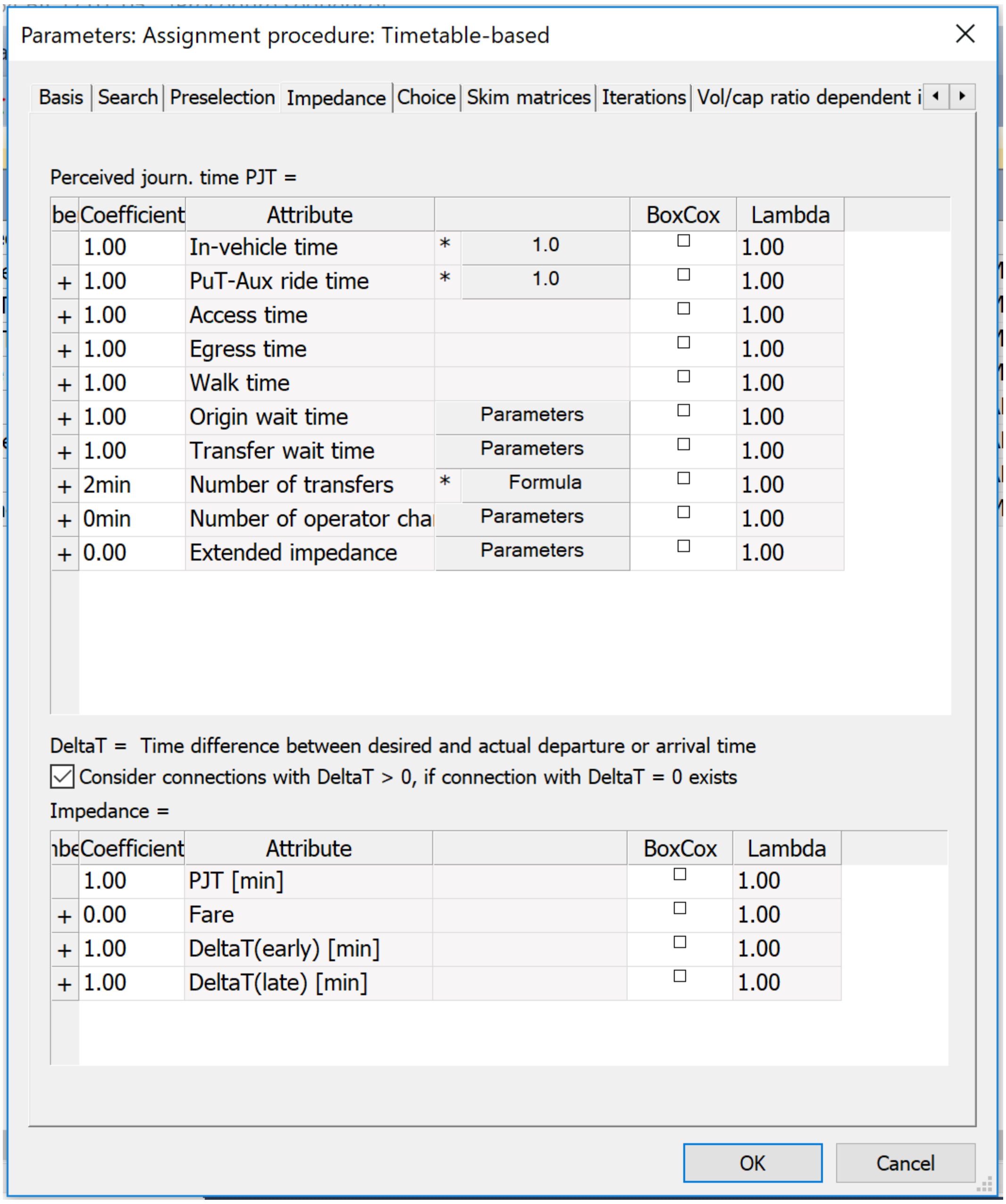
Task 7: Importing GTFS



Task 8: Calculate Skim Matrix for PrT



Task 9: Calculate Skim Matrix for PuT

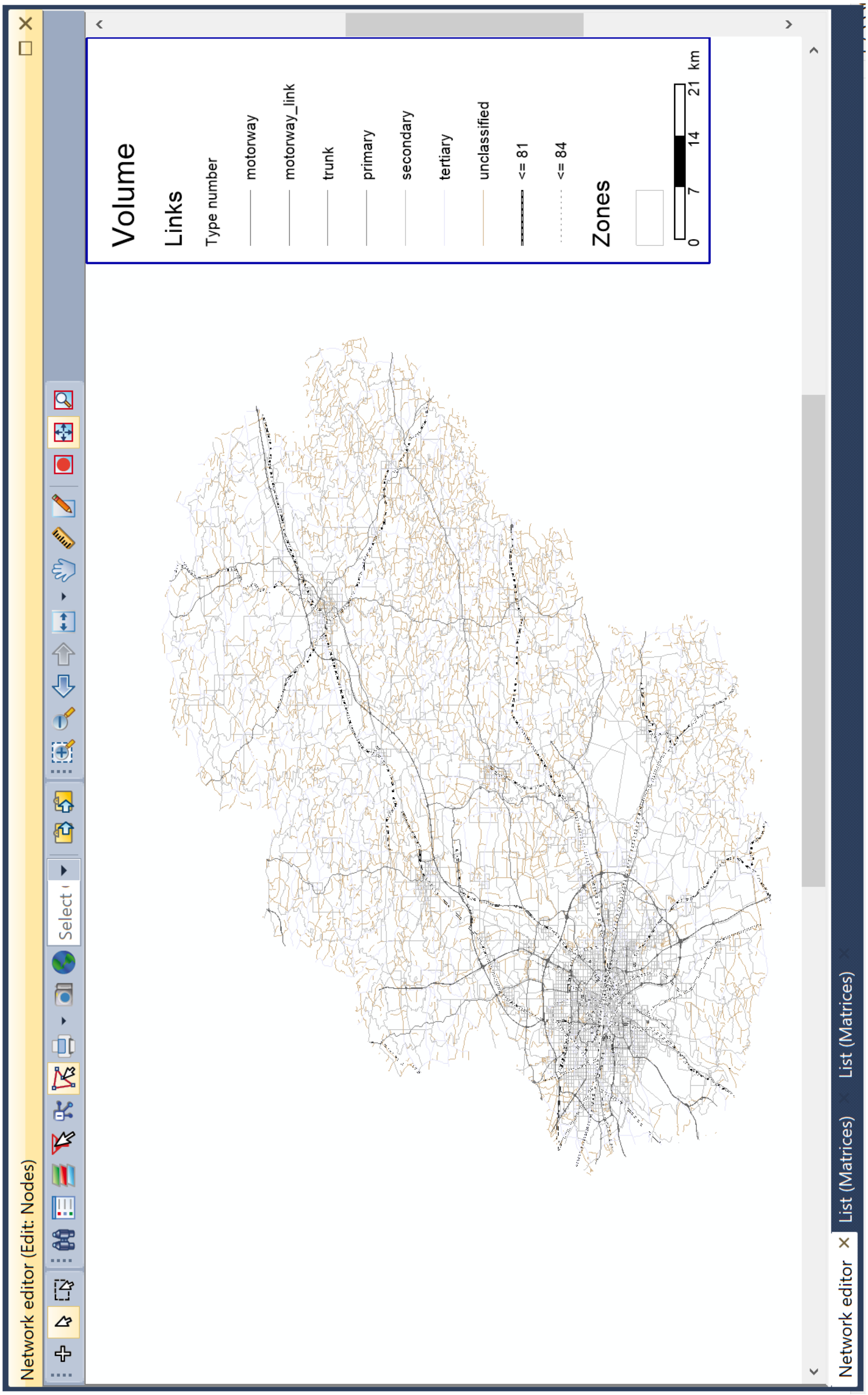


Task 10: List of required Matrices

Matrix filter | Matrix([NO] > 0)

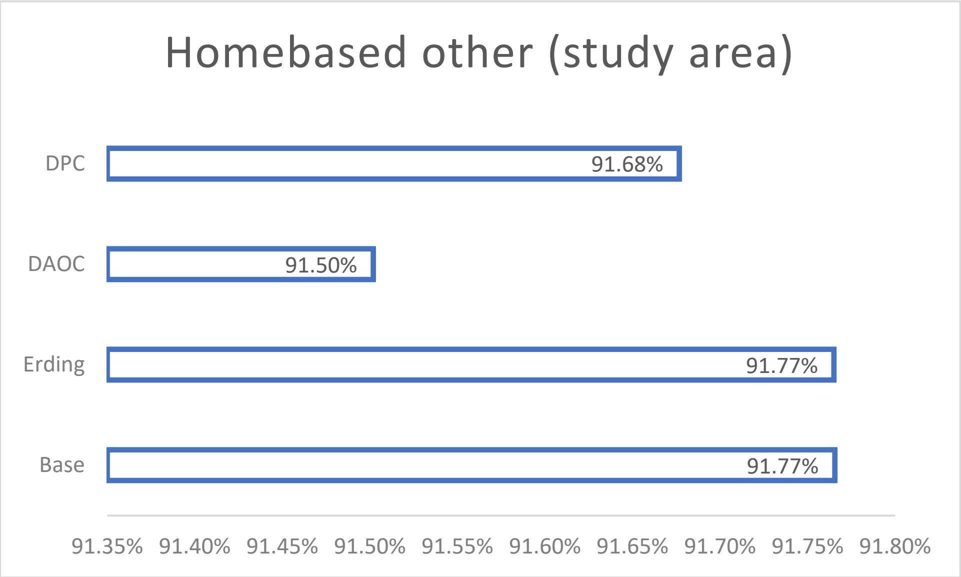
Count: 20	No	Code	Name	MatrixType	ObjectTypeRef	Sum	DSegCode	DataSourceType	Formula
1	1	IVT	In-vehicle time PT	Skim	Zone	2171186504783.352	PT	Data	
2	2	DIS	Trip distance C	Skim	Zone	209019199.482	C	Data	
3	3	TTC	tCur C	Skim	Zone	132143513.108	C	Data	
4	4	ACT	Access time PT	Skim	Zone	2170987743181.847	PT	Data	
5	5	NTR	Number of transfers PT	Skim	Zone	2170977502501.000	PT	Data	
6	6	JRD	Journey distance PT	Skim	Zone	2171110355434.503	PT	Data	
7	8	EGT	Egress time PT	Skim	Zone	2170987638257.237	PT	Data	
8	9	Distribution HA	Distribution HA	OD demand	Zone	17664.939		Data	
9	10	Distribution HO	Distribution HO	OD demand	Zone	856655.000		Data	
10	11	Distribution HW	Distribution HW	OD demand	Zone	503591.000		Data	
11	14		Moduswahl HA x C	OD demand	Zone	11063.559	C	Data	
12	15		Moduswahl HA x PuT	OD demand	Zone	6601.380	PT	Data	
13	16		Moduswahl HO x C	OD demand	Zone	786114.398	C	Data	
14	17		Moduswahl HO x PuT	OD demand	Zone	70540.602	PT	Data	
15	18		Moduswahl HW x C	OD demand	Zone	433406.393	C	Data	
16	19		Moduswahl HW x PuT	OD demand	Zone	70184.607	PT	Data	
17	20	TotalHomebased		OD demand	Zone	668369.538	C	Data	
18	21	TotalHomebased		OD demand	Zone	147326.588	PT	Data	
19	22	C	Car	OD demand	Zone	1347802.635	C	Data	
20	23	PT	PuT	OD demand	Zone	294653.177	PT	Data	

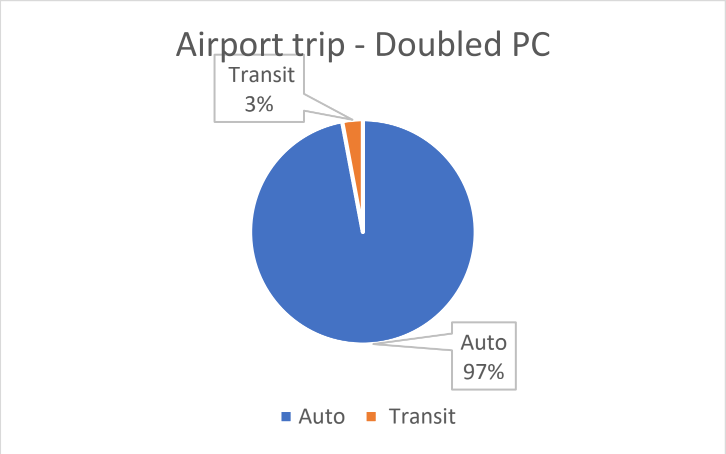
Task 11: Final network modeling

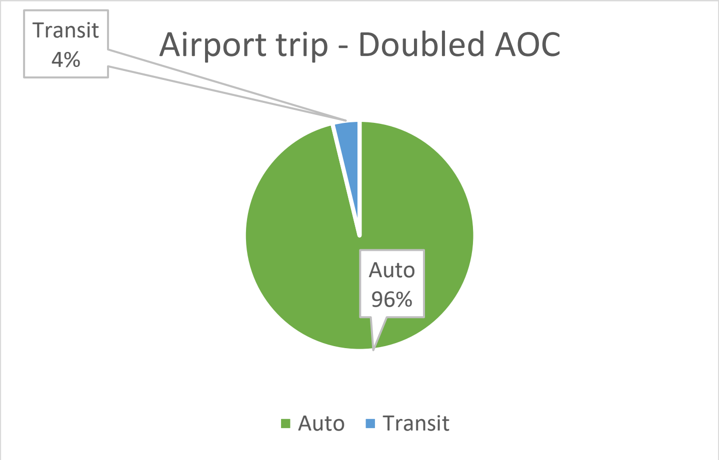


Appendix C

Results of Mode Choice Analysis for Homebased-other trip

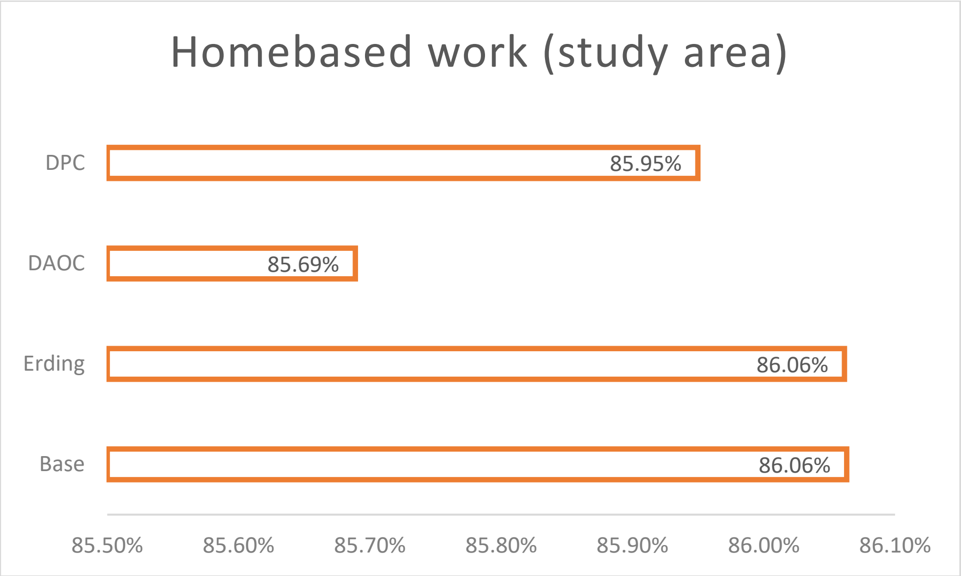


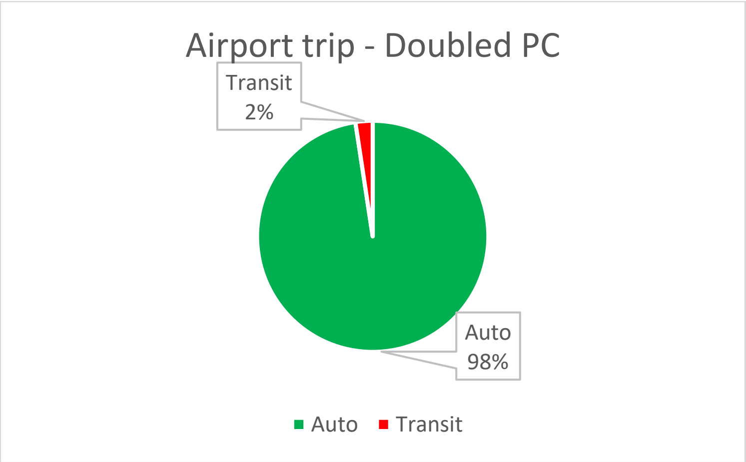


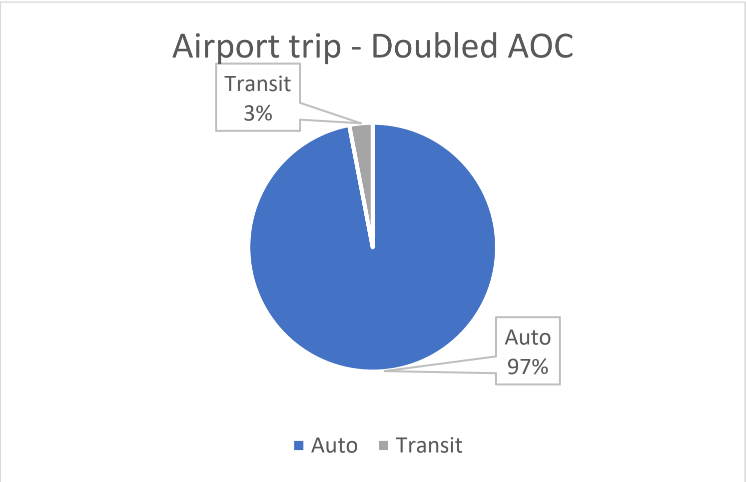


Appendix D

Results of Mode Choice Analysis for Homebased-work trip







Appendix E

Results of Public Transport Assignment in the scenario Erding Ring Closure with Scale Dimension of 10,000 PERS (Based on VISUM)