A comparison between the traditional trip-based traffic demand model and the tour-based model

Analysis of the trip characteristics of the Trefcenter Venlo shopping mall in Limburg

Master's Thesis

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Abstract

Travel demand models have been used over the past decades to solve traffic problems such as congestion and high travel times by focusing on the increase in the capacity of the transport infrastructure. In this context, trip-based models were developed and used incessantly worldwide by traffic modellers and academics. However, the shift to demand management strategies to enhance the efficiency of the transport system has boosted the interest and understanding of advanced modelling, such as the tour-based model (TBM). TBM tries to overcome some limitations of the traditional trip-based model by temporally and spatially interlinking a sequence of trips in a tour. However, even after years of academic progress and knowledge share over advanced models, the trip-based model still widely dominates practice. The complexity and high costs of new models, as well as the scepticism of practitioners are among the reasons of this gap between theory and practice.

Therefore, this research tries to fill in this gap by means of a comparison between the TBM and the trip-based model. Royal HaskoningDHV (RHDHV) has developed a TBM for the province of Limburg in the Netherlands. This model is used in this research aiming to evaluate and demonstrate the potential advantages of the tour-based approach in practice. For this purpose, a trip-based model was developed for the comparison to the TBM of Limburg. More specifically, the trips of visitors of the Trefcenter Venlo shopping mall are investigated. In addition, a travel survey was designed and conducted with the visitors of the mall. This survey is, together with traffic counts, used as the benchmark of the comparison. In other words, the best model is the one that replicates the Shop trip behaviour of the mall closer to the observations on the survey and the traffic counts. To perform a fair comparison, it is important to understand and specify the differences between the developed models. The aim is to make sure that the differences in the results of the models are mainly due to the intrinsic characteristics that distinguish them. That is, the link of trips in tours made by the TBM. Furthermore, four criteria were defined to compare the models. They are the modal split, the trip length, which consists of the travel time and distance frequency distributions as well as the average trip length, the home location of visitors, and trip assignment.

The results indicate that the TBM better replicates the modal shares of both the pre-trips (i.e., Home-Shop trips) and post-trips (i.e., Shop-Home trips) of the visitors. However, this is a consequence of limitations in the development of the models. First, the TBM modal split considerably differs from the survey. The TBM underestimates car trips and overestimates the other modes. This is likely because of the Shop distribution functions which are averaged for various shopping facilities, not distinguishing whether it is in a major city centre or near a highway, where the behaviour of the visitors is different. Improving these functions is expected to enhance the TBM's modal split accuracy. Second, the trip-based model results are hindered by the car distribution functions used in the model, which misrepresent people under 18 years old by enabling them to drive. However, improving it would likely reduce even more the car share of Shop trips in the model, worsening it in the comparison with the survey. Finally, although correcting the aforementioned drawbacks is expected to benefit the TBM, this could not be proved in this research. Thus, the modal split advantage is not exclusively due to the intrinsic characteristics of the TBM.

Moreover, although the TBM estimates the trip length of the visitors of the mall better than the trip-based model, it is not possible to conclude whether this is due to the intrinsic distinction between the two approaches. This is because the trip-based model overestimates car trips by misrepresenting people under 18 years old. This increases the generalised costs of the model

when taking the effects of the demand into account. In addition, the TBM cross-boundary trips are hindered more significantly by increasing the travel costs twice for trips to another country. Improving these issues would change the trip length of the models, but this could not be analysed in this research. Furthermore, the TBM simulates the home location of the visitors of the mall worse. The higher costs for traveling to a different country kept most of the TBM's trips in the Netherlands. This restriction was not observed on the survey, as many visitors come from Germany. However, the disadvantage of the TBM is merely a drawback of this research and different conclusions could be drawn if the cross-border costs were reduced. Finally, the TBM performs better than the trip-based model on the trip assignment criterion. Yet, the results are not good since most of the T-values are not acceptable. Likewise the other criteria, it was not possible to deduce if the better replication of trip assignment is solely due to the intrinsic differences between the models.

To conclude, the comparison of Shop trips performed in this research does not concretely demonstrate the benefits of the TBM over the trip-based model. However, improving the limitations of this research is expected to favour the TBM in the modal split comparison. If this expectation is correct, the TBM is more appropriate to dealing with emerging policies, such as management-oriented policies which aims to incentivise sustainable modes of transport. Nevertheless, this research provides relevant insights to traffic modelling, suggesting improvements to the models. In addition, it pinpoints aspects that deserve further interest, such as the implementation of deterrence functions comprising the different characteristics of the personas, which would increase the behavioural realism of the TBM, and the investigation of NHB trips, which are expected to be better modelled by the TBM.

Preface

The present thesis marks the conclusion of my Master in Civil Engineering and specialization in Transport and Logistics at the University of Twente, Enschede. It has been two challenging but incredible years living in the Netherlands. During the last six months I have dove into the topic of this research, which has broadened my knowledge on the transport modeling field. It has been an exciting and interesting opportunity to apply all the expertise developed since the beginning of my studies.

For this reason, I would like to thank all the professors that have crossed my path since the beginning of my master studies. In addition, I would like to express my special thanks to Erik de Romph and Anna Cristofoli from Royal HaskoningDHV for the enriching discussions and continuous support that were essential for the development of this research. Moreover, thanks to Tom Thomas and Eric van Berkum, supervisors from the UT, for their guidance and feedback that enhanced my knowledge.

My heartfelt gratitude to my dear partner Gabriela, for sharing this journey with me. Her continuous love, support and patience have been invaluable to the accomplishment of this work.

Most of all, I would like to dedicate this thesis to my family. My brother and sister, and especially mother and father. Without their constant encouragement, love and support, this journey would not have been the same. The long distance from home is hard, but I knew they were by my side all the time. Last but not least, my sincere gratitude to my grandfather Eduardo, that sadly passed away during this master process, but I am sure that he is now looking out for me from heaven.

Hugo Bustamante
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1 Introduction

Travel demand models are tools that help decision makers to assess the impacts of transport investments and policies. It provides travel demand information that can be used to forecast travel characteristics in a target year, or evaluate the effects of an infrastructure intervention, for example. Over the past decades, with the accelerated development of the transportation system, the increase in the capacity of the transport infrastructure has been seen as the solution to traffic problems, such as congestion and high travel times. Trip-based models were developed in that context, when the focus in transportation was on the supply side, i.e., the provision of infrastructure was seen as the best solution for the growing travel demand (Sener et al., 2009; Rossi & Shiftan, 1997). However, this solution is not sustainable due to many reasons, such as lack of space, high costs, fossil fuel consumption, and higher levels of congestion caused by induced demand (Sener et al., 2009; Loop et al., 2015).

Therefore, in the last decades, there has been a shift and increased interest in demand management strategies that enhance the efficiency of the transport system (Ferdous, et al., 2011). To name a few, congestion pricing policies, transit-oriented development (TOD), and land-use policies (Sener et al., 2009). Moreover, advanced modelling has been researched, such as tour-based and activity-based models. Initially, the trip-based model has been extended to tour-based models, such as the one developed by Royal HaskoningDHV in Limburg, the Netherlands. These models try to overcome some limitations of the trip-based approach. First, instead of individual trips, the travel unit of tour-based models is a tour, which is a chain of trips starting and ending at the same location. Thus, it addresses trip-level choices more consistently in the mode and space dimensions of travel within a tour (Vovsha, 2019; Bernardin & Chen, 2018). Second, trip-based models poorly estimate non-home-based (NHB) trips, perhaps because by the time they were developed NHB trips accounted for a small portion of urban trips (Bernardin & Chen, 2018). Nonetheless, these models analyse NHB and home-based (HB) trips in parallel, ignoring the connection between them, after all, the vast majority of people return home to sleep in the end of the day (Bernardin & Chen, 2018). This disconnection is overcome by tour-based models. Those limitations hamper the effective evaluation of contemporary and emerging policies by traditional trip-based models. Again, travel demand policies have been shifting from supply-oriented to management-oriented policies (e.g., Travel Demand Management (TDM) or Mobility Management (MM)), which raised questions regarding the effectiveness of trip-based approaches (Esmael et al., 2011).

Furthermore, fully disaggregate models, such as activity-based, have also been developed, spurred by the need for understanding individual travel behaviour, which increases the behavioural realism of the model. Besides the trip-based model limitations addressed by tour-based models, activity-based models go a step further. It combines the tours into a daily schedule, being able to more accurately evaluate the impacts of transport policies specific for time-of-day, such as peak period pricing scenarios, parking disincentive, and flexible work schedules (Sener et al., 2009; Davidson, et al., 2007). These advantages, however, come at the cost of higher complexity. There is no perfect model for transport modellers, and the challenge is to determine how much of this complexity to be incorporated into the model (Milthorpe & Daly, 2010).

However, despite all the progress of travel forecast modelling made in academia during the last decades, trip-based models are still dominantly used in practice, and they are often referred to as four-step models (Castiglione et al., 2014). The complexity due to the level of detail, the amount of data required, the staff capability, and the lack of demonstration of the benefits of those models are some of the reasons why the trip-based approach is still preferred by many practitioners (Rasouli & Timmermans, 2014). One important hindrance for advanced models is that their potential advantages are often restricted to theory, with little practical evidence.

1.1 Research goal

The understanding of travel behaviour and its decision-making process is necessary for accurately forecasting travel demand. This accuracy has become more and more important with the necessity to evaluate specific contemporary policies, as previously mentioned. However, the transition from trip-based to advanced models is still in its infancy, at least in practice. In addition, there is limited research comparing the trip-based and advanced models (Ferdous et al., 2011; Zhong et al., 2015; Kim & Park, 2017). When they exist, they encompass fully disaggregate models. Therefore, this research aims to compare the traditional trip-based model and the tour-based model by means of a local study in the province of Limburg, in the Netherlands, where Royal HaskoningDHV (RHDHV) has developed a tour-based model. The goal is to evaluate and demonstrate the potential advantages of the tour-based approach in practice.

This research attempts to produce a standard trip-based model, repeating what is common practice for traffic modellers. Developing a whole new model to compare with the existing TBM is difficult, especially considering the timeframe of this research. There are several features in the model and multiple decisions to be made while developing it, and each one of them creates distinctions between the two approaches that might influence the outcomes. Thus, it is not easy to assure that differences in the results of the models are only due to their intrinsic characteristics. Nevertheless, this research tries to identify the benefits of the TBM caused by the interlink of subsequent trips in a tour.

2 Research Context

This chapter describes the forecasting mechanisms which are most used for transport planning as identified in literature. These are the trip-based, tour-based and activity-based traffic models. Further, the barriers and opportunities concerning the transition from the trip-based model towards advanced models in practice are discussed. Finally, the knowledge gap and relevance of this research are explained.

2.1 Trip-based model

The trip-based model, which were developed in the 1960s, is an aggregate demand model that attempts to represent the behaviour of more than one individual, such as the inhabitants of certain zones (e.g., neighbourhood), or a population segment (e.g., low-income groups) (Ortúzar & Willumsen, 2011). This model has the trip as the unit of analysis, and they are mostly known as four-step models because of the common distinction between four primary and sequential components (Sener et al., 2009). The four components (i.e., steps) are: (1) trip generation; (2) trip distribution; (3) modal split; and (4) trip assignment, as shown in Figure 1.

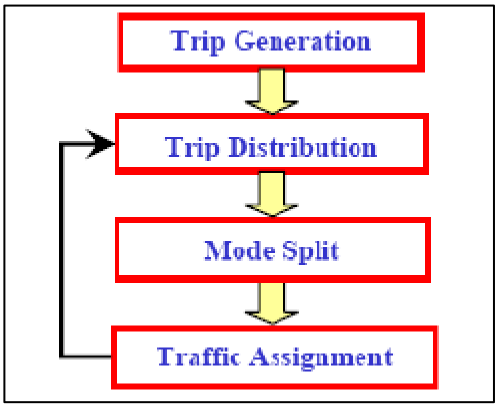

Figure 1: Four-step trip-based model (Sener et al., 2009)

The aim of the trip generation is to predict the number of trips originating in or attracted to a particular traffic zone, for different motives. Further, the trip distribution is the second step of the model, which distributes the total number of trips (output of trip generation) between the zones in a study area. This step is represented by a trip matrix, also called origin-destination (OD) matrix, and is typically done per trip motive. The gravity-model is the most popular approach implemented for trip distribution. The model comes from an analogy to Newton's gravitation law, and uses a distance decay function, also called 'deterrence function', to represent the disincentive to travel with the increase in cost (Ortúzar & Willumsen, 2011). Moreover, the transport mode is chosen in the modal split step. Briefly, the trips between the OD pairs are split according to the different travel modes considered in the analysis. Modal split is one of the most important steps in transport planning, which affects the efficiency of the traffic system (Ortúzar & Willumsen, 2011). Finally, the trip assignment step allocates the demand to the traffic network, following a route choice principle. The outputs of this stage are the link flows and corresponding costs (i.e., travel times). The performance of traffic assignment is usually divided by methods that either consider or not the effects of congestion on travel times.

The trip-based model has been applied and improved for a long time as the understanding of travel decisions has increased. For instance, disaggregate destination choice, as well as household sub-models have been included to reduce aggregation errors (Davidson, et al., 2007). Trip-based models have other important limitations, which are listed below.

- Trip-based model presents intrazonal inconsistency and fails to fully address travel decisions on individual or household level (Davidson et al., 2007; Vovsha, 2019);
- They cannot disaggregate the decisions according to the time of the day (Rossi & Shiftan, 1997);
- Milthorpe & Daly (2010) stated a drawback of trip-based models which is the "inability to attach demographic characteristics to non-home based travel" (p. 1). This is particularly relevant in a scenario of changing trip-making patterns. There has been an increase in the number of NHB trips within the cities, which raised from less than 20% in the past to one third of household trips by 2009 (Bernardin & Chen, 2018). Also, trip-chaining is becoming more frequent (Bhat & Steed, 2002). Therefore, more advanced modelling tools are relevant, such as tour-based or activity-based models.

2.2 Tour-based model (TBM)

Tour-based models (TBM) incorporate temporal and spatial constraints to the trip-based model (Omer et al., 2010). Instead of single trips, TBM consider the linkages between trips within the same tour, as well as the inter-relationship of trips in mode, destination, and time choice (Sener et al., 2009). Thus, TBM are, at least in theory, more accurate and represent reality better than the trip-based model. Figure 2 illustrates a tour consisting of three trips between home, school, and work.

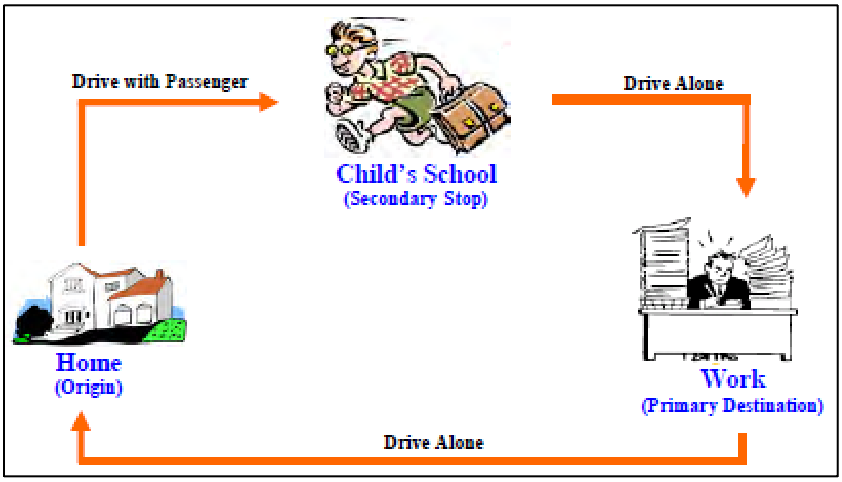

Figure 2: Sequence of trips in a tour-based model (Sener et al., 2009)

TBM have been developed in the 1970's and have been applied in countries such as the United States (U.S.), the Netherlands, Italy, and Sweden (Rossi & Shiftan, 1997; Omer et al., 2010). Furthermore, the distinction between tour-based and activity-based models (ABM) is not always clear in literature. Many authors use the terms interchangeably to refer to the same approach (Zhong et al., 2015; Miller et al., 2005; PTV Group, 2019). However, Rossi & Shiftan (1997) address TBM as a step toward ABM. The authors mention that ABM combine the tours into a daily schedule and require more data than TBM (Rossi & Shiftan, 1997). Additionally, other literature also distinguishes between the two models, although they do not clearly state the differences (Kim & Park, 2017; Sener et al., 2009). Despite the absence of consensus, this research treats tour- and activity-based models differently, inspired by Vovsha (2019).

Regardless the activity chain nature of tour-based models, this research refers to it solely as tour-based. They are disaggregate models developed at person types level, where individuals are grouped by characteristics such as gender, age, and work status. In addition, the destination and mode choices are modelled using either discrete choice models or, as in RHDHV's model, deterrence functions. On the other hand, ABM are here referred to fully disaggregate models, where the analysis is made in the level of individuals and/or households. The ABM description can be seen in Section 2.3.

The advantages of TBM are listed below, and they are not restricted to the chaining of trips into tours.

- TBM incorporate the connection between NHB and HB trips. Bernardin & Chen (2018) enhanced a trip-based model by simply modelling NHB trips dependent on and in series with HB trips. The authors showed that connecting those trips enabled the model to: (1) better replicate NHB trip rates and mode shares with less calibration; and (2) better respond to hypothetical residential development and enhanced transit service.

- The study performed by Esmael et al. (2011) targeted two issues which hinder the effectiveness of trip-based models. These are the shift in travel demand policies to management-oriented policies, and the increase in (PT) travel survey cost. The authors showed that TBM have the potential to decrease this cost, as well as address emerging policies, such as mobility management (MM). According to Esmael et al. (2011), MM policies aim to influence travel behaviour toward sustainable modes of transport. Those policies can be effectively evaluated by monitoring the changes showed by specific groups after the implementation of a mobility measure (Esmael et al., 2011). TBM, such as the one developed by RHDHV in the Netherlands, can better deal with those specific groups (e.g., workers with car).

- TBM have an appealing grouped proportion for modelling travel decisions, which makes it advantageous comparing to fully disaggregate models that face difficulty to 'reconciliate' the disaggregation character with the aggregation of validation – e.g., traffic counts (Vovsha, 2019).

Furthermore, TBM also have limitations, which might explain the reluctance of traffic modellers to apply it in the last decades. These limitations are listed below, and they are overcome by fully disaggregate models, as discussed in the next sub-section.

- TBM do not overcome some of the drawbacks of the trip-based model. TBM as treated here are not sensitive to daily travel patterns since they assume tours are mutually independent, and they do not encompass individual travel decisions (Omer et al., 2010; Vovsha, 2019).

- TBM consider the tours independently. Consequently, they do not recognize the linkages between multiple tours a person can make in the same day, leading to inconsistencies beyond the tour level (Omer et al., 2010; Vovsha, 2019).

- The attractions of TBM (and ABM) are unconstrained. This means that the attractions of a destination might not be totally fulfilled by trips. For instance, consider a badly reachable zone where the number of jobs is 100. It is possible that the model assigns less than 100 work trips to that zone. An iteration scheme is required to solve this issue, which is done in RHDHV's TBM. It is important to mention that this could also be seen as an advantage of advanced models for some purposes. For example, shopping facilities in badly reachable zones may not attract the number of Shop trips that their retail areas suggest.

2.3 Activity-based models (ABM)

Despite the advances in the level of realism obtained with TBM, the ultimate travel behaviour of people is on the individual level. In other words, people make their decisions about where, when, and how they want to participate in activities during the day either individually or with other household members. Thus, ABM are more representative of interactions between household members and how people move through the network. This model assumes that travel demand derives from the desire and need of people to participate in activities (Castiglione et al., 2014). Also, ABM are fully disaggregate models that overcome the limitation of TBM regarding interlinked tours. This makes ABM more interesting for policy analysis of demographic and land-use variables, although also makes it more complex (Zhong et al., 2015).

There are other advantages of ABM over TBM:

- ABM make use of micro-simulation forecasting techniques that enable more consistent linkages across the travel decisions made by people during the day. Hence, it better captures the sensibility of population groups to changes in travel conditions (Davidson, et al., 2007).

- ABM enhance the temporal component of the system by modelling the individual travel behaviour in time windows smaller than 1 hour (Davidson, et al., 2007). This makes the model useful for a wider variety of travel demand policies, such as transportation air quality planning, evaluation of pricing scenarios, and flexible work schedules (Sener et al., 2009).

- ABM encompass not only intra-household interactions, but also in-home activities, being able to model the decision of people of not to travel (Davidson et al., 2007; Omer et al., 2010). This is important considering the impacts of communication technology as well as the increase in the frequency of home office activities after the COVID-19 pandemic.

Furthermore, the limitations of ABM are listed below.

- One of the main problems for the implementation of ABM is its complexity. ABM require not only more data and effort than aggregate models, but also imply higher costs and demand high level of skills from analysts (Kim & Park, 2017; Ortúzar & Willumsen, 2011). In the US, various ABM have been developed, and the shift from trip to tour-based approaches has been considered by several agencies in different cities: Portland (METRO), New York (NYMTC), and San Francisco (SFCTA), among others (Sener et al., 2009). However, there is a resistance for implementation by agencies in the country due to the great data requirements, as well as lack of demonstration that ABM are practical and feasible (Rossi & Shiftan, 1997). Accordingly, Sener et al. (2009) state that the evaluation of the practicality and feasibility of advanced modelling is the first step for ABM implementation.

- Another disadvantage of ABM relates to its intrinsic stochasticity. ABM involve random discrete choices of individuals which requires multiple runs to average the results, lengthening the computational time and increasing data storage (Castiglione et al., 2014; Davidson, et al., 2007). Nevertheless, the necessity for a better modelling of the transport demand and travel behaviour is fundamental for planning agencies. And it is crucial that the theoretical benefits of advanced models are assessed and demonstrated in practice.

2.4 Transition to advanced modelling

There is a gap in the field of traffic modelling between practice and theory (i.e., academia). The trip-based model widely dominates practice, whereas academics prefer the "behavioural realism" of advanced models (Vovsha, 2019). Not only the complexity and high costs of the new generation of models, but also the scepticism and resistance to use by some practitioners have contributed to this gap (Omer et al., 2010; Davidson et al., 2007). It is interesting to note that the first tour-based models were developed more than forty years ago, and they are still rare among practitioners. It demonstrates that filling the gap is not an easy task, and the transition towards advanced traffic modelling needs to be understood. Therefore, this section aims to pinpoint the challenges and opportunities identified in literature for that transition.

Sener et al. (2009) provided a framework for the transition to advanced models. The authors suggested three models according to different timespan. First, a TBM which does not recognize interactions among tours (i.e., tours of a person are treated independently) should be applied in the short-term. Second, in the medium-term, Sener et al. (2009) recommended the TBM which includes the interactions among tours. Differently from the TBM developed by RHDHV, both TBM suggested by Sener et al. (2009) have individuals and households as the unit of analysis. Lastly, for the long-term plan, a system with ABM is suggested by the authors, focusing on individual travel decisions. More recently, Vovsha (2019) described the agent-based model as an extension of ABM, taking full advantage of individual micro-simulation considering, for example, inter-household interactions. It also guarantees that activities and tours of a person are feasible in time and space, which is not true for ABM (Vovsha, 2019). The agent-based model can be seen as an additional step to the transition.

Moreover, the TBM developed by RHDHV is an attempt to make the transition towards ABM models, and it can be added to the transition framework as an initial step. This is because the model is a simplified version of the TBM suggested by Sener et al. (2009), which models groups of people using deterrence functions instead of discrete choice models. Therefore, this research recommends an enhanced transition framework by incorporating additional steps to the framework provided by Sener et al. (2009):

1. TBM developed by RHDHV;
2. Short-term TBM by Sener et al. (2009);
3. Medium-term TBM by Sener et al. (2009);
4. ABM by Sener et al. (2009);
5. Agent-based model by Vovsha (2019).

2.4.1 Challenges

There have been mentioned throughout previous sections several reasons why agencies have not been able or have not had the intention to replace the trip-based model with advanced techniques. The most important ones are listed below as challenges for the transition.

- The complexity of advanced models, especially ABM, usually implies data hungry and longer runtimes (Sener et al., 2009).

- Significant amount of resources is also necessary, not only in terms of money, but also highly skilled personnel (Sener et al., 2009; Bernardin & Chen, 2018).

- Some agencies cannot afford a completely new model, but only the improvements to existing ones (Bernardin & Chen, 2018).

- The risks involved in the development from scratch of innovative transport model. Giving insufficient attention to those risks hinders the planning and controlling of the project (Kiel, et al., 2021). In this regard, Kiel et al. (2021) identify several risks that can be encountered in the development of new transport models. They evaluated the problems that caused delays in the construction of the Stravem (**Stra**tegisch **Ve**rkeersModel **M**idden-Nederland) model by the Province of Utrecht. The authors state various risks that project developers should be aware of. These are, among others, insufficient insight into the requirements of the stakeholders, much disagreement between client and stakeholders due to poor assessment framework, and temporary or definitive departure of employees.

- Scepticism of practitioners as well as lack of empirical evidence of the advantages of advanced models (Omer et al., 2010; Rasouli & Timmermans, 2014).

- Although travel choices are mostly individual (or household) decisions, aggregate constraints to validate the models are still necessary to the equilibrium of the demand and supply in the transport system. For instance, the aggregate capacity constraints imposed on the decisions to travel of an individual – e.g., job competition or opening/closing hours of facilities – or network capacity constraints (Vovsha, 2019). This shows that it is still important to consider aggregate characteristics to a certain extent, which makes the tour-based approach attractive. This is, at the same time, a challenge for fully disaggregate models and an opportunity for TBM.

2.4.2 Opportunities

This sub-section highlights the opportunities identified in literature for the transition towards advanced traffic models. These opportunities are listed below.

- The necessity for advanced models that address specific policies have been growing and putting pressure on practitioners, which can help to spur the transition. These policies include, among others, the assessment of pollutant emissions, energy consumption, and pricing and toll scenarios (Davidson, et al., 2007).

- The organisation of workshops and seminars which includes academics and practitioners has been giving professionals the opportunity to become familiar with the new modelling techniques (Rasouli & Timmermans, 2014). This might help to eliminate part of the scepticism existing in practice.

- Highly detailed information of trips has been acquired lately, where “big data” can be advantageous for the transition (Vovsha, 2019).

- Technological development is also important to fill the gap and help traffic modellers to move forward to individual travel behaviour models. For instance, the inclusion of Autonomous Vehicles (AVs) in travel models might not be possible with traditional trip- or tour-based models due to their inflexibility (Vovsha, 2019).

- One important obstacle to fully disaggregate models relates to their validation, as aforementioned. The comparison of individual travel choices with aggregated real-world data might not be reliable (Vovsha, 2019). Thus, this appears as an opportunity for TBM.

2.5 Existing model comparisons

It is also essential to understand what has been achieved so far to surpass the transition. This is possible by analysing the attempts to demonstrate the benefits of advanced models. Few comparisons between different models exist, and they are mostly contrasting trip-based models with ABM. Zhong et al. (2015) compared the outcomes of each step of a trip-based model with the ABM for Tampa Bay Region in Florida. For the trip generation step, the authors found that the trip-based model poorly captures NHB trips because of the significantly lower rates obtained with the model for these trips. Regarding the trip distribution step, the trip length distribution curves are similar, but a significant difference was observed for the average trip length of the models. This average length varies depending on the purpose. The modal split comparison showed that the trip-based model underestimates driving trips and cannot capture alternative modes such as taxis and non-motorized modes. Finally, in the trip assignment step, the ABM performed worse since it underestimates link flows.

Another comparison was made by Ferdous et al. (2011). The authors compared a trip-based model with the ABM for Columbus, Ohio. They performed the comparison for the regional- and project-level (local-level analysis for specific projects implemented in the city) for three scenario years. The results showed that the ABM performed slightly better overall for the regional-level for most of the attributes, including vehicle ownership levels, work start time distribution, workflow distribution, and average travel time for work trips. In the project-level, the results were similar for the models.

The few comparison studies developed so far are not sufficient to draw definitive conclusions about the advantages of advanced modelling techniques. In addition, no literature comparing TBM with trip-based or fully disaggregate models was found, which reinforces the necessity for further research for the transportation modelling field. As a contribution, this research analyses how the trip-based and TBM replicate shopping trips of a mall in the Netherlands. The decision for analysing a shopping mall is because shopping trips correspond to one of the highest numbers of daily trips in the Netherlands, together with work and business (CBS, Onderweg in Nederland (ODiN), 2019). Besides that, the share of non-work urban trips, of which the majority are shopping trips, has been increasing even in peak periods, which hinders a common assumption that attributes traffic congestion to commuting trips only (Pawar et al., 2021; Bhat & Steed, 2002). On the other hand, NHB-work trips are largely for shopping and eating (Schultz & Allen, 1996). Moreover, many people combine their shop activity with other daily trips, especially when automobile is available (Ye et al., 2007). Trip-chaining is becoming more prevalent nowadays due to rapid changes of the population's socio-demographics and employment characteristics (Bhat & Steed, 2002). Additionally, Milthorpe & Daly (2010) showed that approximately 25% of HB shopping trips involved at least one intermediate activity in Australia (i.e., were part of a tour). The effects of these trip chains are an issue for trip-based models, and TBM may show improvements for modelling the trip patterns in a large demand point such as a shopping mall.

2.6 Knowledge gap

According to literature, there exist several research on the alternatives to enhance traditional trip-based traffic models. Despite that, it becomes clear that they are not yet sufficient for practitioners to switch from trip- to tour-based or activity-based model. The reasons are not only the complexity of advanced models, but also the lack of demonstration of their benefits in practice. This demonstration is seen as the best way to promote and encourage the use of new generation of models (Davidson, et al., 2007). Although literature predominantly indicates the theoretical advantages of TBM over conventional trip-based models, this research tries to confirm it for a case study in the Netherlands.

Moreover, the shift of contemporary policies to management-oriented measures is jeopardising the effectiveness of conventional trip-based models. Additionally, travel behaviour and the response to implementation of emerging policies are becoming more complex, which demand data with higher spatial resolution for effective evaluation of those policies (Esmael et al., 2011). Therefore, more behaviourally realistic models such as RHDHV's TBM, as well as the understanding of how those models respond to the policies are needed.

Furthermore, this research is also relevant to the field due to the limited literature comparing trip-based and advanced models. To the best of my knowledge, there is no comparison study performed for a tour-based model as treated here. The existing research compare trip-based with fully disaggregate models (i.e., ABM), as discussed in Section 2.5. Thus, this research contributes to the understanding of the potential advantages of TBM. It is important to point out that this research corroborates with the first step of the transition to advanced models, as discussed in Section 2.4, which might facilitate the transition process for practitioners.

3 Research Structure

This section presents the structure of the research. It first enumerates the research questions and sub-questions, followed by the description of the case study. Finally, the methodology describes how the research questions will be answered through this research.

3.1 Research questions

The overarching research question in this research is:

> ***What are the benefits of the tour-based traffic demand model over the classic trip-based model for the analysis of the trip characteristics of a shopping mall in the province of Limburg?***

This main research question encompasses the potential advantages of using a tour-based traffic model. This will be assessed by zooming in on a shopping mall area located at the province of Limburg, in the Netherlands. Thus, this research focusses on the characteristics of trips generated and attracted by this mall, which will be analysed and compared for both the trip- and the TBM. Furthermore, to answer the main research question, three research sub-questions, plus sub-sub-questions, are formulated as follows:

1. *What is the actual travel behaviour of visitors of the shopping mall?*
    a. *How can the travel behaviour of the visitors of the mall be obtained?*

The first sub-question encompasses real observations that are necessary to compare the trip-based model with the TBM. They are needed for establishing a benchmark where the models' outcomes can be compared to. In this research, this is done by means of a travel survey and traffic counts. The survey will be conducted with visitors of the shopping mall and aims to understand the trip characteristics of those visitors. Also, traffic counts over the whole network will be used to assess the overall performance of the models in relation to the assignment of trips.

2. *How does the development of the models ensure a fair comparison?*
    a. *How does the tour-based model differ from the trip-based model in Limburg?*
    b. *How can the differences in the development of the models affect their performance in relation to the survey and traffic counts?*

Sub-question 2 and its sub-questions address how the trip-based and the TBM are developed for the research in Limburg. For this purpose, it is essential to understand the similarities and differences between the two approaches, developing and refining them appropriately to guarantee a fair comparison. A fair comparison means that the distinction on the models' performance in comparison to the survey and traffic counts is primarily due to their intrinsic characteristics, and not due to a poorer development of one of them. Therefore, sub-question 1b targets the identification and assessment of the contrasts in the development of the trip- and tour-based models.

3. *What are the advantages and disadvantages of the tour-based model when replicating the shop trips at the mall?*
    a. *How can the potential benefits of the tour-based model be evaluated?*
    b. *What is the overall benefit of applying the tour-based model in Limburg?*

Finally, sub-question 3 focusses on the comparison between the two models. First, four comparison criteria are defined to evaluate the potential advantages of the TBM. The criteria will be compared to the survey results and traffic counts in order to determine the best model technique. This is the model for which the criteria are closer to the observations, which indicates that the model better replicates the trips of the mall. It is important to mention that the comparison will be made with the outcomes of the models without calibration. This is to avoid the criteria to be biased by observations and the calibration method. To add to that, it is worth to refer again to the improvements of a trip-based model made by Bernardin & Chen (2018), which resulted in more accurate results with less calibration. Moreover, sub-sub-question 3b) aims to assess the overall advantages of applying the TBM.

3.2 Case study

Royal HaskoningDHV has been developing the tour-based model in the Netherlands for the province of Limburg. This research will use that model to perform a local study on the Trefcenter Venlo shopping mall, located in the city of Venlo, as can be seen in Figure 3. Trefcenter Venlo is one of the largest shopping centres of Limburg, with approximately 40 stores – including shop and catering – and a free parking facility. Many visitors are attracted by this indoor mall not only by car, but also by public transport, since Trefcenter is near several bus stops.

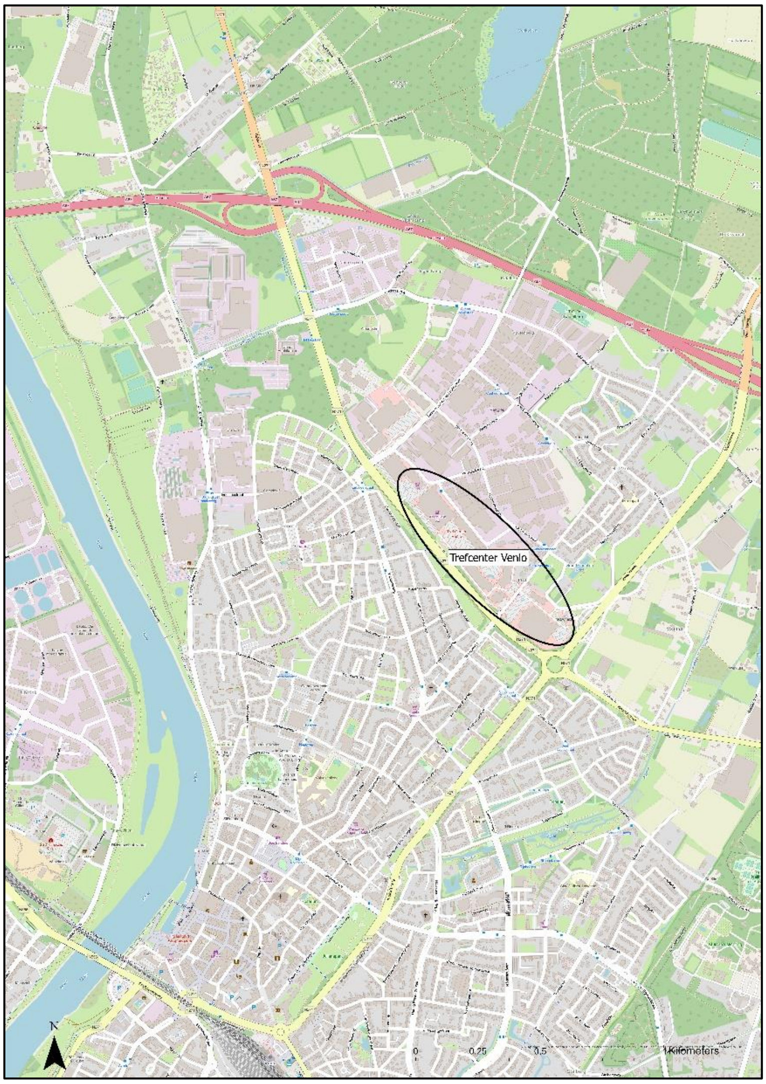

Figure 3: Trefcenter Venlo shopping mall and surroundings

Trefcenter Venlo was selected for this study due to its size and location, which makes it an important demand point in Limburg. The mall is close to the A67, which is an important motorway connecting the Netherlands and Germany. In addition, Venlo is located right on the German border, attracting many visitors from that country. It should be mentioned that RHDHV's model includes Germany, Belgium, and France in the zoning. Therefore, the trips of German visitors can also be addressed, even though in a lower level of detail due to larger German zones.

3.3 Methodology

The three research sub-questions stated above will be answered according to the methodology presented in this section. Thus, each sub-section of the methodology targets one question. First, the travel survey is explained, which illustrates the travel behaviour of the visitors of the mall. Second, sub-question 2 is answered by describing how the models were developed. Finally, the comparison criteria to answer sub-question 3 are presented. The methodology structure can be seen in Figure 4.

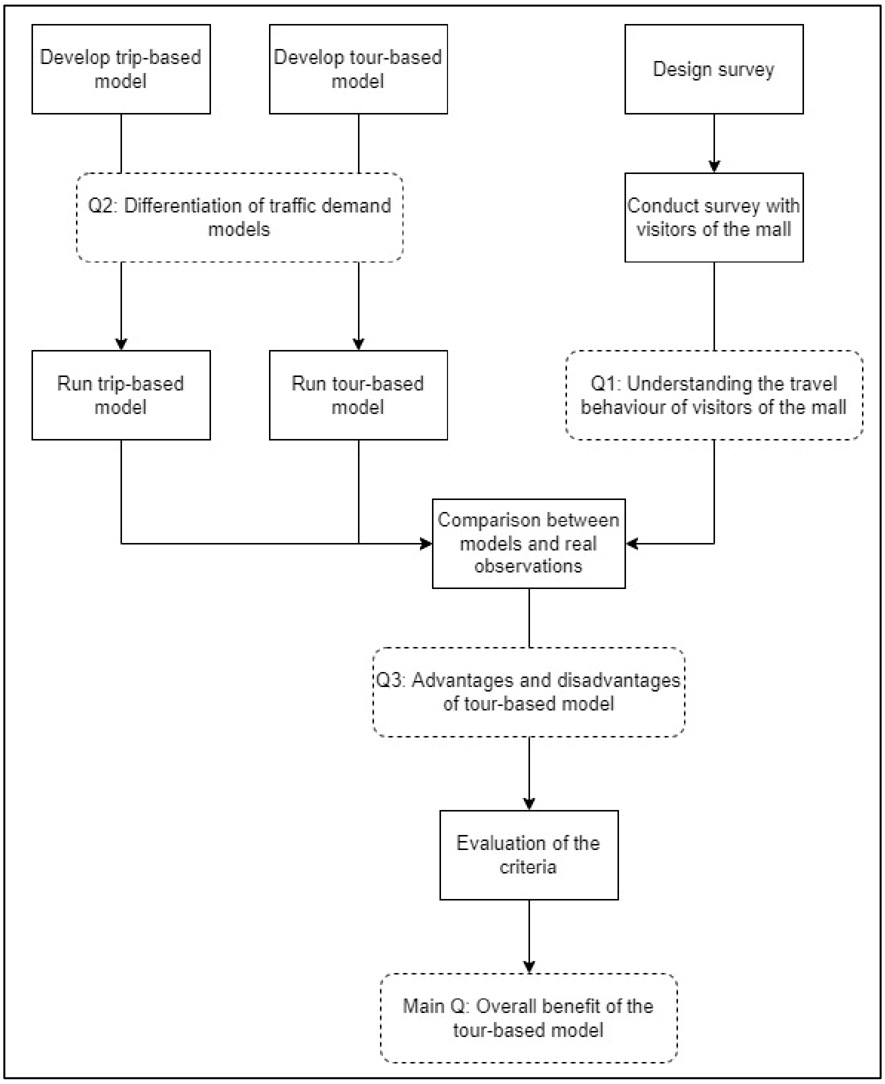

Figure 4: Simplified framework of research methodology, including research questions. Solid-line boxes represent methodology step. Dashed boxes represent research questions addressed at corresponding stage.

3.3.1 Travel survey

A travel survey was developed to be conducted with the visitors of the Trefcenter Venlo shopping mall. The objective is to use it as a benchmark representing the observations of the trip characteristics in that location. Therefore, it is important to gather sufficient amount of data – i.e., have enough respondents.

The survey consists of a questionnaire to be asked for random visitors at the mall, and can be found in Appendix A. It was initially designed aiming to obtain the activities performed by the visitors in their previous and next stop, as well as the transport modes of the trips to and from the mall (Questions 5-8). In addition, the postal code, travel time, and distance questions (Questions 1, 3-5, 9 and 10) were added. These additions are important to observe the trip length (e.g., trip length distribution and average trip length), and the origin or destination of the HB trips. It should be mentioned that only the four numbers of the Dutch postal code were asked due to privacy concern. This is not an issue for German postal codes since they are not as accurate as the Dutch PC6 level, for example. Furthermore, the travel time and distance questions are not mandatory since it is preferred to have empty responses than inaccurate answers of doubtful people. Moreover, the alternatives for mode of transport include not only the modelled modes. This gives additional information for the analysis of the trips, even though some responses might be excluded from the comparison of the models. Finally, Question 2 was added to make sure that only Shop trips are included in the comparison. This is because it is possible that some respondents work at the mall (or even do business).

Furthermore, the survey was performed by DUX, a company specialized in surveys and research (DUX, n.d.). The day to conduct the survey was chosen aiming to avoid holidays in the Netherlands and Germany, which could lead to unusual travel behaviour. In addition, the travel behaviour on Mondays and Fridays might not be adequate due to the proximity to weekends. Therefore, the survey was conducted between 9:00 and 18:00 on Thursday, 9th of June. In total, 456 people responded to the survey. The responses are discussed in Section 4.1.

3.3.2 Development of models

Sub-question 2 encompasses the description of how both the trip- and the tour-based models are developed, as well as what is needed to ensure a fair comparison. Thus, the understanding of the similarities and differences between the models is needed. Therefore, this section first discusses the common aspects of the models. Subsequently, the description of how the TBM and the trip-based model work is given. Finally, the most important differences between them are highlighted.

3.3.2.1 Common aspects of models

The common characteristics of the models are described in this section. They correspond to the zoning, the modes of transport, and the day periods.

1. **Zoning**

Before introducing each modelling technique, it is important to discuss the common features shared by them. Firstly, the Limburg model contains 1888 zones. They are relatively small-scale areas within the province which gradually enlarge to farthest regions, including not only the rest of the Netherlands, but also Germany, Belgium, and France (see Figure 5).

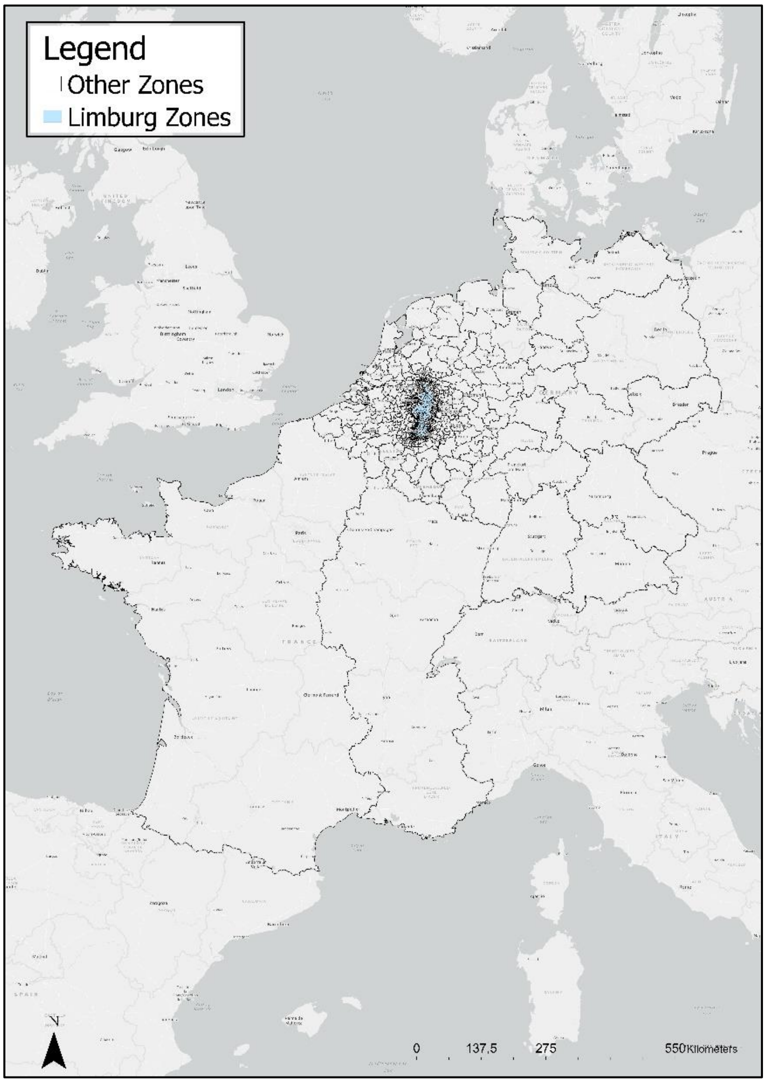

Figure 5: Zones of the Limburg model

Zooming in the city of Venlo, where the mall is located, Figure 6 shows the zones and corresponding centroids. The mall is located in a zone with 395.76 ha[1]. Based on the socio-economic attributes of the zone (see Table 50 – Appendix D), it is possible to observe a mixed land-use in the region, with various industries, residences, and a school. This was confirmed by investigating the area using Google maps and Google Street View. More importantly, since this research investigates Shop trips, a thorough inspection was made aiming to find any other relevant shopping location that could interfere on the analysis of the mall's trips. If this was confirmed, a split in the original zone would be necessary. Since no relevant shopping facility was found, it is safe to assume that all Shop trips from and to that centroid are concentrated at Trefcenter Venlo.

[1] 1 ha = 10,000 m²

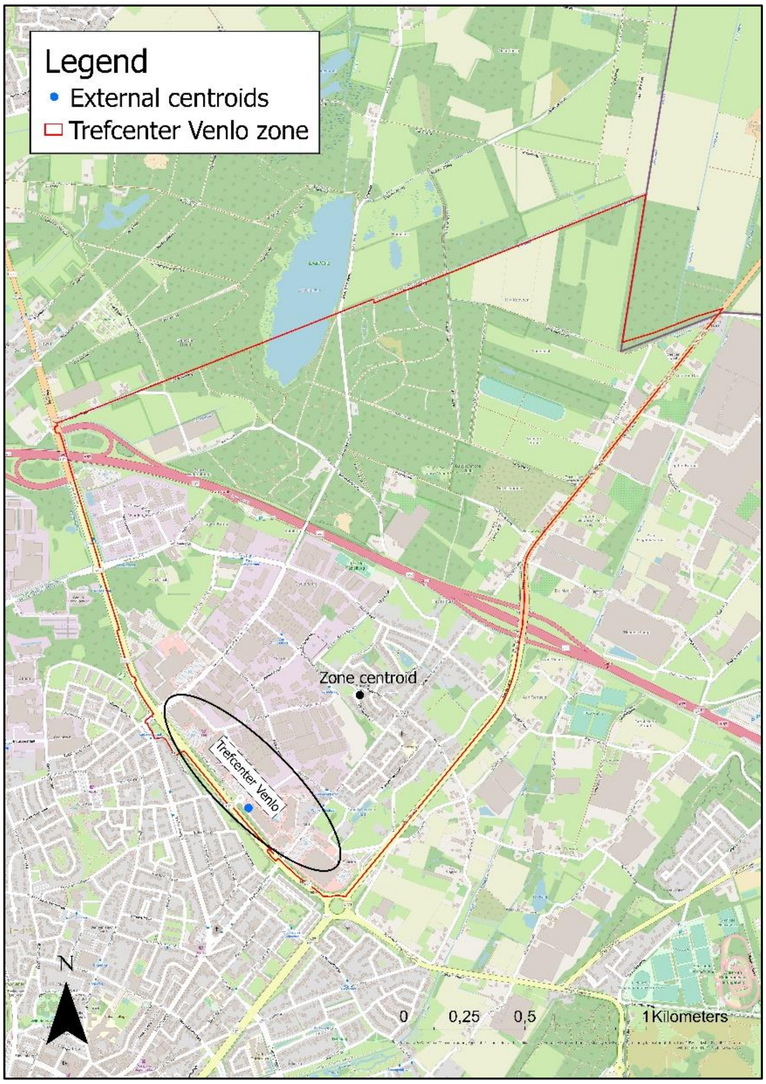

Figure 6: Zone of Trefcenter Venlo

Moreover, an external centroid is also placed within the zone. It corresponds to the fast-food restaurants KFC and McDonald's, which are part of Trefcenter. External centroids were added to the Limburg's model to consider points of interests which attract significant amount of people and are not properly represented by the "normal" zone. They attract trips of the purpose Other and include, amongst others, catering facilities, theatres, and hospitals. A decision of including or not KFC/McDonald's into the mall's zone was required. Thus, KFC/McDonald's centroid was grouped to Trefcenter because there is no interest in people going from the mall to KFC/McDonald's or vice-versa.

2. Modes of transport

Secondly, this research is performed for passenger transport, including three modes of transport, which are car, bicycle, and public transport (PT). Freight is also relevant for the prediction of traffic demand and certainly influences traffic flow. To take that into consideration, the freight demand – for which the calculation is the same for both models – is added to the models before assigning the trips to the network.

3. Day periods

Thirdly, the day periods are defined. They correspond to the morning peak (Morning), evening peak (Evening), and rest of the day (Rest). In addition, a 24-hour period is also defined and consists of the aggregation of all other day parts. It should be highlighted that PT was entirely modelled for the 24-hour period. This was done to reduce computational time and agreed with the client (i.e., Province of Limburg) by the time of the development of the model.

3.3.2.2 Functioning of models

Having discussed the commonalities between the tour- and trip-based models, the detailed description of how they work is given in this section. The combined flowchart of the models is presented in Figure 7.

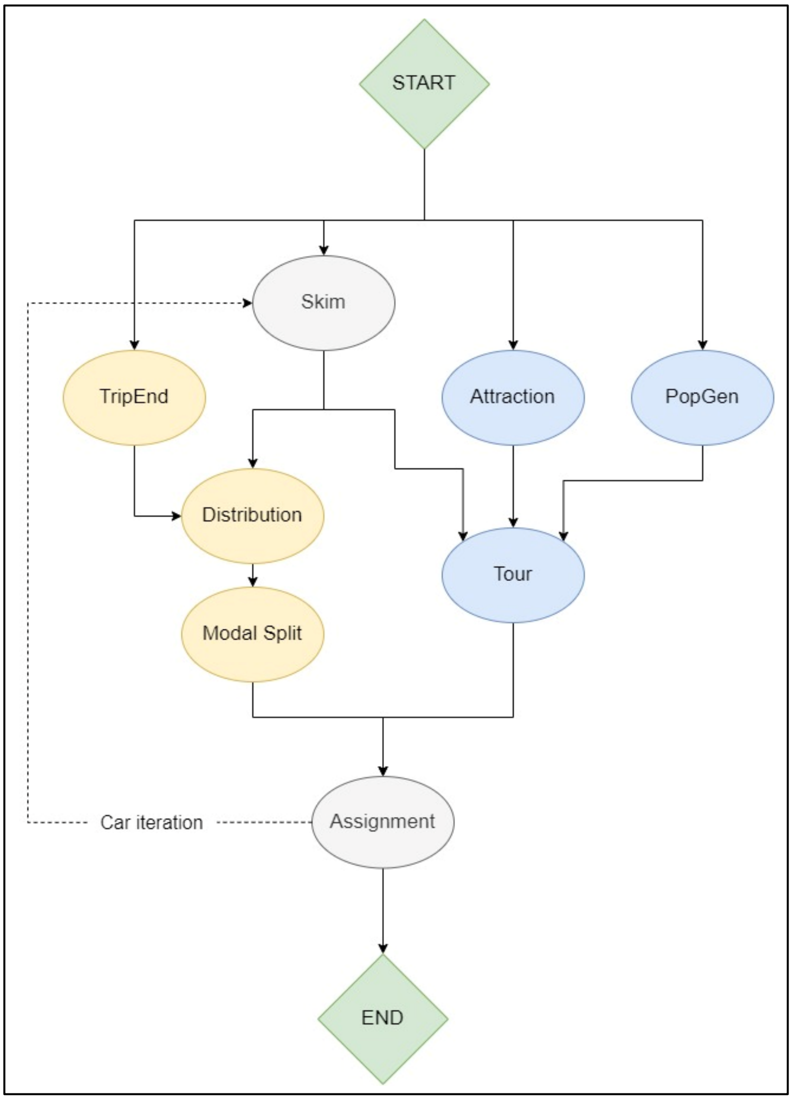

Figure 7: Combined flowchart of models

The light-grey spheres correspond to the sub-models common to both approaches, which are described in Appendix B. The blue spheres represent the sub-models that are exclusive of the TBM, which are described in Section 3.3.2.2.1. The yellow spheres represent the exclusive models of the trip-based approach, described in Section 3.3.2.2.2. Note that the dashed line represents the iteration that occurs only for cars, which aims to take the effects of congestion into account (see Section 2 – Appendix B).

3.3.2.2.1 Tour-based model

The inhabitants of the zones are disaggregated into person types in the TBM. Thus, the behaviour of the trips is estimated separately for each person type (also called personas). These personas include the characteristics age, work status, income level, and car ownership (see Table 1). This resulted in 72 personas. However, the number of personas was limited to improve computation efficiency. This was done by adding some categories together, reducing to 42 person types.

Table 1: Person characteristics and categories that form person types

Characteristics	Categories
Age	0-17; 18-34; 35-65; 65+
Work status	None, Part-time, Full-time
HH-income (€)	< 30k; 30-50k; > 50k
HH-car ownership	Yes; No

The following sub-sections describe the exclusive sub-models of the TBM (i.e., blue spheres in Figure 7).

1. **Attraction**

The attractions are determined based on the attraction variable of the zones, such as number of jobs and retail spaces. This is multiplied by coefficients derived from OViN data and is calculated according to Equation 1 (Aimsun SLU, 2021). These coefficients differ per degree of urbanization (see Appendix E), day part and trip purpose.

$$T_i^t = \sum_k f_{ik}^t * SE_{ik} \tag{1}$$

Where:

T_i^t = number of trips produced by or attracted to zone i in day part t;
f_{ik}^t = coefficient for zone i and k-th socio-economic attribute for day part t;
SE_{ik} = value of k-th socio-economic attribute for zone i.

In this sub-model, the production coefficients are set to zero, hence only the attraction is computed. The trip production of the TBM is determined in the Tour sub-model (sub-section 3 below).

2. **Population Generation (PopGen)**

The PopGen sub-model computes the population of each zone corresponding to the 42 personas. For this purpose, the model uses socio-economic attributes as input. It combines the categories of the different person characteristics computing their corresponding values. Basically, the model fills in a 4-dimensional matrix for each zone, where the characteristics are the dimensions, and the socio-economic attributes are the totals of the rows or columns. Since there are various manners to fill in the matrix, initial values derived from OViN are used to optimize the calculations.

3. **Tour**

The Tour sub-model encompasses not only the distribution and modal split steps, but also, as previously mentioned, it determines the production of each zone.

a. Trip production

The combinations of personas and tour types, which is formed by a sequence of activities, are called strata. The frequencies of occurrence of the strata are input for the Tour sub-model and were determined based on OViN. This frequency is used to calculate the trips produced by each zone, as in Equation 2. A distinction in the degree of urbanization is also made for the frequencies.

$$T_i = \sum_{pt} Pop_{pi} * Freq_{pti} \tag{2}$$

Where:

$Pop_{pi} =$ population of zone i for person type p;
$Freq_{pti} =$ the frequency of tour t for person type p in zone i.

After that, the attractions obtained in the Attraction sub-model are balanced to the productions. The balancing aims to match the number of trip departures and arrivals (Aimsun SLU, 2021).

b. Trip distribution and modal split

The destination and mode of transport are simultaneously determined in the Tour sub-model. It uses deterrence functions derived from OViN. Thus, based on the cost of traveling from an origin i to a destination j, the willingness $F(Z_{ij}^{mapu})$ is determined according to the value on the deterrence function. These functions differ per transport mode (m), persona (p), activity (a), and urbanization degree (u).

The distribution and modal split are performed as follows. For an origin centroid i, for each stratum, the willingness is calculated for all destinations and modes. This willingness is first determined for the primary activity[2]. For a certain destination j, this is calculated for back-and-forth trips to the origin – which is the Home location as all tours start at home. It is important to emphasise that the transport mode defined for the primary activity is used in the whole tour. Thus, the TBM does not encompass change of modes within a tour. Further, the willingness ($F(Z_{ij}) + F(Z_{ji})$) is multiplied by the attraction for the activity in destination j, resulting in the utility of that OD-relation and mode. Subsequently, this utility is used to obtain the probability of choosing destination j, and mode m, calculated according to Equation 3. Finally, this probability is multiplied by the production of i (T_i, from Equation 1), resulting in the trips between i and j to get the number of travellers who will make the tour.

$$Prob_{ij}^{m} = \frac{U_{ij}^{m}}{\sum_{k \in K} U_{ik}^{m}} \tag{3}$$

Where:

$k =$ destination among all alternative destinations K from zone i.

For the secondary activities within the tour, the willingness is calculated by adding the willingness between the primary and secondary activities to the willingness between the secondary activity and Home. Further, this willingness is multiplied by the attraction for the

[2] Primary activity is determined based on the following order of hierarchy: WBEDSO. However, in case there are 3 intermediate activities in a tour (e.g., HWSOH), the primary activity is the middle one (i.e., S). This is because the algorithm only checks the pre- and post-activities to reduce complexity.

activity, and the trips distributed to each secondary destination is obtained as explained in the previous paragraph for the primary activity.

The Tour sub-model calculates the tours for the 24-hour period. As last step, these tour trips are split into the different day parts using activity-pair factors. These factors differ per persona and transport mode and were derived from OViN.

3.3.2.2.2 Trip-based model

The trip-based model consists of the sequential sub-models: trip generation, trip distribution, modal split, and trip assignment. The output of one step is used as input for the following one. The exclusive sub-models of the trip-based model are described in the following sub-sections.

1. Trip End

The Trip Generation sub-model, also known as Trip End, works similarly to the Attraction sub-model in the TBM. However, in the trip-based model the production coefficients are also estimated. Thus, it calculates the number of trips produced and attracted per zone. They are calculated according to Equation 1. After that, the productions and attractions are balanced. For this purpose, the balancing method must be previously defined for each trip purpose. The methods vary among fixing or freeing the arrivals and/or departures. If the arrivals are free and departures fixed, the arrivals will be modified (i.e., multiplied by a balancing factor) to match the departures and vice-versa. In case both are free, the arrivals and departures will be modified to match the mean value of the two (Aimsun SLU, 2021). In the trip-based model the HB purposes are fixed on the home side. In addition, both the arrivals and departures are free for purposes Business and Other.

a. Car Availability

Car availability enables to distinguish travellers between the ones that have access to a car (which may choose whether using it or not), and those who do not have access to a car (which can only travel by bicycle or PT) (Aimsun SLU, 2021). In the TBM this distinction is already made on the personas. However, the trip-based model distinguishes it as follows.

Basically, the balanced trips produced and attracted by each zone are split between Car Available (CA) and No Car Available (NCA). This split is made in Aimsun based on the percentages of CA $\pi_{ip}^{(CA)}$ for each zone and purpose.

$$T_{ip}^{(CA)} = \pi_{ip}^{(CA)} * T_{ip} \tag{4}$$

$$T_{ip}^{(NCA)} = (1 - \pi_{ip}^{(CA)}) * T_{ip} \tag{5}$$

Where:

$T_{ip}^{(CA)}$ = CA trips, produced or attracted, for zone i and purpose p;
$T_{ip}^{(NCA)}$ = NCA trips, produced or attracted, for zone i and purpose p;
T_{ip} = total trips, produced or attracted, for zone i and purpose p.

The CA percentages $\pi_{ip}^{(CA)}$ are calculated based on the different household types in the zone. Three household types are distinguished according to car ownership. Those are households with no car (h_1), households with one car (h_2), and households with more than one car (h_3). In addition, for each purpose, the car availability percentage $\pi_{hp}^{(CA)}$ and average number of trips $\bar{T}_{hp}$ are pre-defined per household type (see Table 2). These values were derived from OViN. They determine the average amount of trips when car is available as follows:

$$\bar{T}_{hp}^{(CA)} = \pi_{hp}^{(CA)} * \bar{T}_{hp} \tag{6}$$

Where:

$\bar{T}_{hp}^{(CA)}$ = average number of CA trips for household type h and purpose p.

Table 2: Attributes of household types per purpose

Purpose	$\pi_{h_1}^{(CA)}$	$\pi_{h_2}^{(CA)}$	$\pi_{h_3}^{(CA)}$	$\bar{T}_{h_1}$	$\bar{T}_{h_2}$	$\bar{T}_{h_3}$
Home-Work	0	83	89	0.41	0.54	0.58
Work-Home	0	83	89	0.41	0.54	0.58
Home-Shop	0	60	75	0.43	0.56	0.78
Shop-Home	0	60	75	0.43	0.56	0.78
Home-Education	0	5	25	0.43	0.56	0.78
Education-Home	0	5	25	0.43	0.56	0.78
Other	0	60	75	0.43	0.56	0.78
Business	0	83	89	0.39	0.52	0.55
Home-Business	0	83	89	0.39	0.52	0.55
Business-Home	0	83	89	0.39	0.52	0.55

Further, the CA percentage is determined by averaging the number of trips and CA trips of household h with the household shares of a zone, and dividing these values as follows:

$$\pi_{ip}^{(CA)} = \frac{\sum_h \pi_i^h \bar{T}_{hp} \pi_{hp}^{(CA)}}{\sum_h \pi_i^h \bar{T}_{hp}} \tag{7}$$

Where:

π_i^h = percentage of household type h in zone i, determined according to Table 3.

Table 3: Household share calculation depending on car ownership

Household car ownership (HCO_i)	> 1 car ($\pi_i^{h_3}$)	1 car ($\pi_i^{h_2}$)	0 car ($\pi_i^{h_1}$)
< 0.4	$0.05 * CO_i$	$0.95 * CO_i - \pi_i^{h_3}$	$1 - \pi_i^{h_2} - \pi_i^{h_3}$
$0.4 – 0.8$	$0.2 * CO_i - 0.06$	$0.8 * CO_i + 0.06 - \pi_i^{h_3}$	$1 - \pi_i^{h_2} - \pi_i^{h_3}$
$0.8 – 1.0$	$0.3 * CO_i - 0.14$	$0.65 * CO_i + 0.18 - \pi_i^{h_3}$	$1 - \pi_i^{h_2} - \pi_i^{h_3}$
$1.0 – 1.2$	$0.3 * CO_i - 0.14$	$0.35 * CO_i + 0.48 - \pi_i^{h_3}$	$1 - \pi_i^{h_2} - \pi_i^{h_3}$
> 1.2	$0.4 * CO_i - 0.26$	$0.15 * CO_i + 0.72 - \pi_i^{h_3}$	$1 - \pi_i^{h_2} - \pi_i^{h_3}$

The household car ownership is based on the centroid car ownership (per 1,000 inhabitants) and the average household size H_i in a zone:

$$HCO_i = \left(\frac{CO_i}{1000}\right) * H_i \quad (8)$$

Finally, after splitting the trips, a new balance occurs for both CA and NCA.

2. Trip Distribution

The Trip Distribution step consists of distributing the trips produced and attracted among the zones of the study area. Within Aimsun, three methods are available to calculate the distribution, which are the Growth Factor Model using Furness algorithm, the Gravity Model, and the Destination Choice Model. This research uses the popular Gravity Model for distributing the trips. The general form of the gravity model can be seen in Equation 9. It uses a deterrence function $f(c_{ij})$ which represents a disincentive to travel with the increase in cost (Ortúzar & Willumsen, 2011).

$$T_{ij} = \alpha O_i D_j f(c_{ij}) \quad (9)$$

Where:

T_{ij} = number of between zones i and j;
α = gravitational constant;
O_i and D_j = generated and attracted trips from respective zones.

The deterrence function can have several forms, such as exponential, power, and combined deterrence functions. They differ per mode of transport. Therefore, for each OD pair, the values of the functions are combined (i.e., added up) in the distribution. Moreover, the cost involved in the deterrence function corresponds to the generalised costs which are outputs of the Skim sub-model. In addition, O_i and D_j comes from the Trip End. The gravitational constant can be replaced by two balancing factors A_i and B_j, leading to Equation 10.

$$T_{ij} = A_i O_i B_j D_j f(c_{ij}) \quad (10)$$

The doubly-constrained gravity model applies an iterative process to make the sum of all trips from an origin i to all destinations equal to the determined trip production for that origin in the previous step. Similarly, the sum of trips from all origins to destination j are made equal to the determined trip attraction for that destination. This process is a modified Furness algorithm which ensures the convergence to a balance between the sum of the origins and the sum of the destinations (Ortúzar & Willumsen, 2011). The stop criterion for this method can be set as a maximum of iterations or when the difference between A_i or B_j (Equations 11 and 12) from the current iteration and the previous iteration converges to ε (set by the user). In this research, a maximum of 100 iterations was defined.

$$A_i = \frac{1}{\sum_{j=1}^{z} B_j D_j f(c_{ij})} \quad (11)$$

$$B_j = \frac{1}{\sum_{i=1}^{z} A_i O_i f(c_{ij})} \quad (12)$$

Furthermore, the outputs of the distribution step are OD matrices per trip purpose and day part. These matrices also distinguish between CA and NCA. Optionally, the purposes can be aggregated into a total matrix. Those matrices are input for the Modal Split sub-model.

3. Modal Split

The Modal Split is the step where the transport mode is chosen. It uses the OD matrices from the trip distribution as input and generates matrices for the different modes. To determine the modal split in the trip-based model, a multinomial logistic regression model is used. It is a discrete choice model that calculates the probability for each mode based on deterrence functions. In this research, the same deterrence functions of the Trip Distribution step are used for the modal split. Thus, the probability of using mode m to travel from zone i to zone j is calculated as in Equation 13.

$$Prob_{ij}^{m} = \frac{U_{ij}^{m}}{\sum_{m \in M} U_{ij}^{m}} \tag{13}$$

Where:

U_{ij}^{m} = utility of traveling with mode m from zone i to zone j;

M = set of all transport modes.

It should be mentioned that the probabilities are calculated only for bicycle and PT for NCA trips. Finally, to determine the number of trips for each mode, the matrices of the Trip Distribution step are multiplied by the corresponding probabilities. Thus, the car trips result from the multiplication of CA trips by the (CA) probability of car being used. On the other hand, the bike and PT trips are calculated according to Equation 14.

$$T_{ij}^{m} = T_{ij}^{(CA)} * Prob_{ij}^{m\,(CA)} + T_{ij}^{(NCA)} * Prob_{ij}^{m\,(NCA)} \tag{14}$$

Where:

T_{ij}^{m} = trips between zones i and j for mode m (bike or PT).

3.3.2.3 Differences between the models

This section discusses the main differences between the trip- and tour-based models. First, differences that could affect the comparison are pointed out. They are the purposes, OViN data used to estimate the parameters of the models, and car availability. Finally, the intrinsic differences between the models are highlighted.

3.3.2.3.1 Purposes

One major difference between the two models developed in this study relates to the trip purposes. In the TBM developed by RHDHV for the province of Limburg the trip purposes are called activities. Moreover, the tours consist of a number of activities, which forms the various tour types contained in the model. The activities included in this model can be seen in Table 4. The Delivery activity corresponds to the motive “pick-up/drop-off” of people (not packages).

Table 4: Activities included in the tour-based model

Activity	Notation
Home	H
Work	W
Business	B
Delivery	D
Education	E
Shop	S
Other[3]	O

The sequence of activities determines the various tour types that can be modelled. For instance, Home-Work-Home (HWH), Home-Work-Shop-Home (HWSH), and so forth. However, in order to reduce the computation time, the amount of tour types is limited. This is done by: (1) converting tour types with 4 or more intermediate activities into tour types with 3 activities, since the frequency of tours with 4 or more activities is lower than 1.6%; (2) limiting the number of activities between Home and the primary activity, as well as before or after the primary activity, to one; and (3) simplifying tour types according to the frequency they occur per person type (< 1%), e.g., students that are full-time workers yield almost no trip. It is important to mention that for all these three procedures, the criterion for removing activities from the tours is the length of stay, i.e., the activity with the shortest stay is removed. It is important to point out that all tours start and finish at home.

Moreover, the purposes defined for the trip-based model are shown in Table 5.

Table 5: Trip purposes defined for the trip-based model

Purpose	Notation
Home-Work	H-W
Work-Home	W-H
Home-Shop	H-S
Shop-Home	S-H
Home-Education	H-E
Education-Home	E-H
Home-Business	H-B
Business-Home	B-H
Business	B
Other	O

The differences on the purposes between the two models limit the comparison among them. Firstly, the gravity model's purposes do not enable a distinction between HB and NHB trips. This is because purpose Other is the aggregation of all NHB trips (except Business), H-O and O-H in the trip-based model. Therefore, purpose Other is surrounded by uncertainties in that model due to the combination of, among others, Work, Education, and Shop trips (e.g., W-E, W-S, S-O). Nonetheless, the disaggregation of H-O and O-H could solve this issue. However, this was not possible since it would require a laborious task of deriving parameters, which would not fit into the research time frame. In addition, this disaggregation is not common practice, and a deviation from the standard way these models are developed is not desired.

[3] Based on OViN the purpose Other in the TBM includes visit/stay, touring/walking, sports/hobby, other leisure activities, services/personal care, other purpose.

Secondly, the Delivery purpose is included in the purpose Other for the trip-based model. Its disaggregation was initially considered but for similar reasons it was kept out of the scope of this research. Since Delivery represents a small portion of trips, this might not significantly affect the outcomes.

Despite this purpose difference, the TBM enables the generation of the output matrices according to activity pairs defined by the user. Thus, it is possible to group the activity pairs according to the purposes of the trip-based model, which allows for analyses per purpose between the two models.

3.3.2.3.2 OViN data for parameter estimation

Another difference between the two approaches concerns the various parameters used as inputs to the models, which were derived from different data sources. The TBM is a recent model which used OViN from 2018, while the most recent trip-based model available at RHDHV (called here old trip-based model) had the parameters estimated from OViN 2015-2017. This difference can strongly influence how the models behave, hence affecting the comparison as aimed in this research. Therefore, some decisions were taken to reduce as much as possible the consequences of having different OViN data, trying to guarantee similar starting points for the models. The decisions taken in the Trip Generation and Trip Distribution step of the trip-based model are discussed in the following sub-sections.

1. **Trip Generation**

The first adjustments in the trip-based model parameters were made in the Trip Generation step. In theory, this step should yield the same outcomes for both models. However, this was not possible due to the purpose differences previously explained. Therefore, the attraction and production parameters of the trip-based model were adapted as follows.

a. **Attraction coefficients**

The attraction coefficients used to calculate the trips attracted to each zone were copied from the TBM. The purposes were aligned to the destination activity as shown in Table 6. For instance, the TBM attraction coefficients of activity Work were used for purpose Home-Work in the trip-based model. This was not done for purposes Business and Other since the activity pairs aggregated in these purposes largely differ from the TBM, as already explained. Therefore, the attraction coefficients of the old trip-based model were used for Business and Other purposes.

Table 6: Purpose matching

TBM	Trip-based model
Work	Home-Work
Shop	Home-Shop
Education	Home-Education
Business	Home-Business
Home	Work-Home
Home	Business-Home
Home	Shop-Home
Home	Education-Home

Moreover, the coefficients of activity Home were multiplied in the trip-based model by the percentages in Table 7 for the highlighted purposes. These percentages were derived from OViN 2018 and corresponds to the share of trips to home per activity pair.

Table 7: Share of trips to home

Activity pair	Percentage
W-H	29%
B-H	1%
S-H	23%
E-H	13%
D-H	6%
O-H	27%

b. Production coefficients

Furthermore, the production coefficients of the old trip-based model were used for all purposes. This is because the purpose differences do not allow for aligning the tour- and trip-based models in the origin activity, as done for the attraction. The coefficients of the old trip-based model had been estimated for the socio-economic attributes presented in Table 8.

Table 8: Attributes of the old trip-based model

Attributes (Dutch)	Attributes (English)
ArbeidsplaatsenIndustrie	Industry workplaces
ArbeidsplaatsenDetail	Detail workplaces
ArbeidsplaatsenOverig	Other workplaces
ArbeidsplaatsenZorg	Care workplaces
ArbeidsplaatsenHoreca	Catering workplaces
ArbeidsplaatsenOnderwijs	Education workplaces
ArbeidsplaatsenDienstverlening	Services workplaces
Inwoners	Inhabitants
Leerlingplaatsen	Study places
Workers	Workers

These attributes do not match the attributes of the modelled zones since the TBM is more detailed and contains more socio-economic attributes for each zone. Therefore, the production coefficients were duplicated to match the zone attributes according to Table 9. For example, the coefficients of the old trip-based model derived for “Other workplaces” were used not only for that attribute, but also for “Agriculture workplaces” and “Government workplaces” (see highlighted cells). The attributes used to calculate the productions and attractions of each model can be found in Tables 51 and 52 – Appendix D.

Table 9: Attribute matching

Zones attributes (Dutch)	Zone attributes (English)	Old trip-based model attributes
ArbeidsplaatsenLandbouw	Agriculture workplaces	Other workplaces
ArbeidsplaatsenIndustrie	Industry workplaces	Industry workplaces
ArbeidsplaatsenDetail	Detail workplaces	Detail workplaces
ArbeidsplaatsenDiensten	Services workplaces	Services workplaces
ArbeidsplaatsenOverheid	Government workplaces	Other workplaces
ArbeidsplaatsenOverig	Other workplaces	Other workplaces
ArbeidsplaatsenZorg	Care workplaces	Care workplaces
ArbeidsplaatsenHoreca	Hospitality workplaces	Catering workplaces
ArbeidsplaatsenOnderwijs	Education workplaces	Education workplaces
LeerlingplaatsenBasis	Basic study places	Study places
LeerlingplaatsenVoortgezet	High school study places	Study places
LeerlingplaatsenMBO	MBO study places	Study places
LeerlingplaatsenHBO_WO	HBO/WO study places	Study places
KindplaatsenKDVBSO	Child study places	Study places
Inwoners	Inhabitants	Inhabitants
ArbeidsplaatsenIndustrieLaag	Low industry workplaces	Industry workplaces
ArbeidsplaatsenDienstenLaag	Low services workplaces	Services workplaces
ArbeidsplaatsenZorgLaag	Low care workplaces	Care workplaces
Werk Parttime	Part-time workers	Workers
Werk Fulltime	Full-time workers	Workers

Three additional corrections were made to the production coefficients, which are listed below.

- First, the old trip-based coefficients for "Study places" did not include trips of children up to 12 years old. Thus, the coefficients of attributes "Basic study places" and "Child study places" were increased in 29% for purpose Education-Home. This value corresponds to the average number of trips per children per day in Limburg (CBS, 2018).

- Second, the old parameter calculations did not include primary students. Therefore, the total "Study places" in the Netherlands were increased by 1.48 million (CBS, 2018).

- Third, the number of workers in the zones are divided between full-time and part-time workers. These attributes are used to calculate the production of purposes Home-Work and Home-Business. According to OViN 2018, the number of H-W trips of part-time workers is approximately 74% of the trips of full-time workers. This value is 41% for H-B trips. Thus, the part-time workers coefficients were multiplied by these percentages.

2. Trip Distribution

The deterrence functions of the TBM were also used for the trip-based model in the Distribution step. These functions are derived per purpose, transport mode, and car availability. The HB purposes used the functions corresponding to the non-home activity. For example, the TBM function of activity Work was used for purposes Home-Work and Work-Home in the trip-based model. In addition, purposes Business and Other of the trip-based model used the functions of the corresponding TBM activities.

Moreover, adaptations in some functions were required in the trip-based model due to another important difference between the models, which is the calculation of intrazonal trips. The usual calculation for most zones happens in the distribution stage as for all other OD relations. That is, the trips are distributed considering the value on the deterrence function, which is determined based on the generalised cost of the OD relation. However, this can be an issue for large zones as they may contain intrazonal costs sufficiently high to yield null deterrence. In theory, this means that the trips generated by those zones cannot be distributed to anywhere, not even internally. This is indeed inconsistent in the trip-based model, hindering its distribution. However, the TBM circumvents it by calculating the surface of the deterrence function instead, enabling intrazonal trips. Therefore, to solve this problem in the trip-based model, the deterrence functions of large zones had to be adjusted for high costs. This was done by setting the right tale of the functions to values close to but different from zero (i.e., 0.001). It is important to mention that this was done for car functions when car is available, for purposes Work, Education, and Shop. In addition, PT functions were adapted when car is not available for purposes Business, Education, Shop, and Other.

3.3.2.3.3 Car availability

Another difference between the models concerns car availability. Both models take into consideration if people have car available to travel. However, they deal with it slightly differently. Car availability is included in the TBM as a characteristic of the person types, which is based on whether people have car available or not in the household. On the other hand, the trip-based model determines car availability based on the number of cars available in the zones, as well as on average household size. In addition, it distinguishes household types among no car, 1 car, and 2 or more cars. Unfortunately, it is not possible to correlate car availability in the models because the matrices of the TBM do not distinguish it rather than in the personas.

3.3.2.3.4 Intrinsic differences between models

The aforementioned decisions made are expected to alleviate the distinctions that could influence the outcomes of the comparison in this study. However, it is important to highlight the intrinsic differences between the trip- and tour-based models to achieve the goal of this research. These differences are discussed below.

1. **Production calculation**

The trips produced by the zones are calculated differently by the two models. The trip-based model uses the socio-economic attributes of the zones depending on the trip purpose. Thus, for trips which the starting purpose is different than home, the model considers features such as workplaces, study places or number of workers. On the other hand, the TBM's production depends solely on the population of the zones and their tour frequency.

2. **Distribution of trips**

The primary intrinsic difference relates to how the models distribute the trips. As already mentioned, the trip-based model treats them independently, while the TBM links a sequence of trips in a tour. In addition, the TBM determines the locations of secondary activities using the previous and the next destination in the tour. This secondary activity does not exist in the trip-based model. In reality, the trips between primary and secondary activities (i.e., NHB trips) are aggregated in purpose Other in that model, as already mentioned. These core distinctions are desired to be the main cause of deviations in the replication of trips by the models, which would allow for drawing conclusions regarding the advantages of the TBM. Thus, it is essential to properly address those differences when comparing the models.

3. **Modal split**

The last intrinsic difference is the modal split. The TBM assigns a transport mode to the primary activity and this mode is used for the whole tour. In the trip-based model each trip has a mode, which can even be inconsistent in the way back trip since they are not interlinked.

3.3.3 Comparison criteria

The third research sub-question encompasses the structure of the comparison between the models. Four criteria were chosen for this comparison, of which three are compared to the survey's results as in Section 3.3.3.1 and one is compared to traffic counts as in Section 3.3.3.2.

3.3.3.1 Comparison with survey

The criteria to be evaluated and compared to the survey's results are described in this section. These criteria are used to analyse the HB trips attracted to the mall and HB trips produced by the mall. In other words, the Home-Shop and Shop-Home trips are investigated. Therefore, two comparisons can be made per criterion, corresponding to the pre- and post-trips of the visitors of Trefcenter Venlo.

1. **Modal split**

The first criterion aims at the comparison of modal shares. As already stated, the mode shares of a traditional trip-based model were better replicated when the NHB trips were linked to HB trips (Bernardin & Chen, 2018). Thus, it is interesting to investigate mode shares, especially if many visitors of the mall are in a tour, which can favour the TBM.

In order to determine which model is better, the Root Squared Error (RSE), inspired by Ferdous et al. (2011) will be used. The closer the criterion is from the survey observations, the better the model. This means that lower RSE indicates that the model fits better to the survey. The RSE is calculated as follows:

$$RSE_{mt} = \sqrt{\left(MS_{survey}^{mt} - MS_{model}^{mt}\right)^2} \tag{15}$$

Where:

MS_{survey}^{mt} = mode share of transport mode m and time period t according to survey;
MS_{model}^{mt} = mode share of transport mode m and time period t according to model.

The average RSE between all transport modes is finally calculated to determine the best model for this criterion. Again, the best model is the one with the lowest average.

2. **Trip length**

The second criterion corresponds to the trip length. First, the trip frequency distribution of travel time and distance are compared according to the percentage of trips within the pre-defined classes. These classes were defined for the survey questions (see Appendix A) and can be seen in Table 10. The frequency distributions will be compared based on the RSE of each class. More specifically, the average RSE between all classes will be calculated, as in the modal split criterion.

Table 10: Classes for trip frequency distribution comparison

Class	Travel time [min]	Distance [km]
1	< 5.0	< 1.0
2	5.0 – 10.0	1.0 – 2.0
3	10.0 – 20.0	2.0 – 5.0
4	20.0 – 30.0	5.0 – 10.0
5	30.0 – 40.0	10.0 – 20.0
6	> 40.0	> 20.0

Moreover, in addition to the distributions, the average distance and travel time of the visitors' trips will also be measured. Although they can significantly vary depending on the transport mode, the survey sample size does not allow for the comparison per mode. This criterion was inspired by Kim & Park (2017), and is calculated according to Equation 16. The closer the model's average value is to the observed on the survey, the better.

$$AvgCost = \frac{\sum_i \sum_j c_{ij} * t_{ij}}{n} \quad (16)$$

Where:

c_{ij} = travel time or distance between zones i and j with mode m;
t_{ij} = number of trips between zones i and j with mode m;
n = total number of trips.

It is important to mention that since the responses of the survey do not contain the exact travel time or distance of the trips, the middle value of the classes was used to calculate the average trip length. This was done not only for the survey, but also for the models. For the last class, conservative values of 50 minutes and 30 kilometres were chosen.

3. Home location of visitors

The third comparison will be made geographically. This criterion aims at analysing how the models simulate where the visitors of the mall live. For this purpose, the postal codes obtained by the survey will be linked to the model zones and these locations will be investigated. This criterion was chosen since the main distinctions between the models are expected to be in the distribution of the trips, due to the intrinsic differences mentioned in Section 3.3.2.3.4. Therefore, it is interesting to analyse where the models assign the HB Shop trips of Trefcenter Venlo to. Finally, conclusions can be drawn in case there is a pattern on where the visitors live.

3.3.3.2 Comparison with traffic counts

An additional comparison is made for the trips assigned to the network. For this purpose, the trips assigned by the models are compared to traffic counts throughout the network.

4. Trip assignment

The last criterion compares the T-values between the models' assignment and the traffic counts over the whole model for the 24-hour period. For this purpose, three classes are defined as seen in Table 11. The best model is the one that has lower "Not good" level.

Table 11: Categories of T-values

T-value	Level
T < 3.5	Good
3.5 < T < 4.5	Acceptable
T > 4.5	Not good

4 Results

This section presents and discusses the results of this research. First, the results of the survey are discussed. Subsequently, the results of the trip-based model and TBM are presented. Finally, the comparison between the models is made according to the defined criteria.

4.1 Survey results

The results of the survey are presented and discussed in this section. In total, 456 people responded to the survey. Not all responses were complete. As expected, many visitors did not know the travel time or distance of their trips. About 45 responses have empty travel time and/or distance questions. Also, some additional corrections in the survey results were necessary, which are summarized in Table 12.

Table 12: Corrections made in the survey results.

Issue	**Correction**	**Reason**
1 response without pre-activity	Set to Home	Travel time, distance, and mode equal to post-trip (which was Home)
10 responses without post-mode	Set to Car (driver)	All visitors went driving to the mall.
4 responses with two options marked for activity at mall	3 set to Shop and 1 to Work	All visitors marked Shop, but one of them works at the mall. Thus, Work was maintained for that respondent.
High number of Shop as post-activity[4]	Post-activity set to the same as pre-activity (i.e., Home) for visitors with post-trip travel time below 5 minutes and distance below 1 km. In addition, their travel times, distances, and transport modes were also aligned to their pre-trip.	Travel time and distance distributions indicate a misinterpretation of the question by respondents due to the predominance of short trips (see Figures 53 and 54 – Appendix F). Also, 12% of the visitors going to another shop marked walking as their next mode (even when they went by car). Thus, it is likely that they stated their next activity as another store inside Trefcenter.

Furthermore, approximately 28% of the visitors were in a tour, i.e., the pre-activity was different from the post-activity. Additionally, almost 10% of the visitors are from outside the Netherlands. Two of them came from Belgium and 43 from Germany. Figure 8 shows the activities of the visitors at the mall.

[4] This issue was also checked for the pre-trips. However, the trip length distributions are mostly higher than the expected for who is travelling inside the mall (see Figures 51 and 52 – Appendix F). Thus, it is assumed that they were indeed at another shop facility before going to Trefcenter.

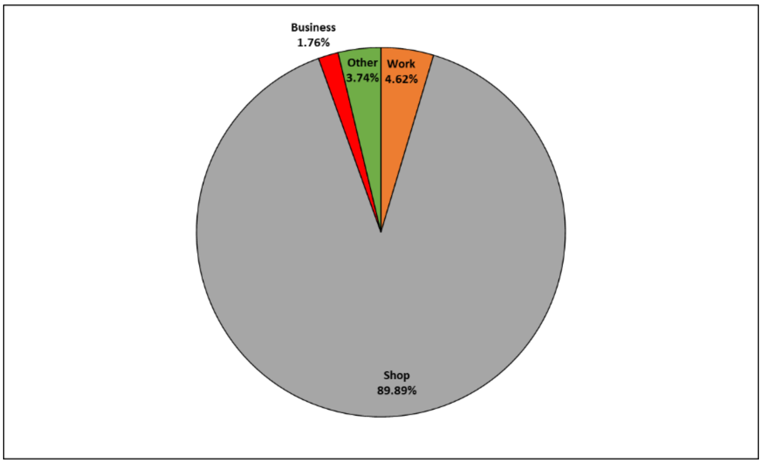

Figure 8: Activities of visitors at the mall (after corrections)

Almost 90% of the visitors travel to Trefcenter for shopping. As expected, some respondents work at the mall and their responses are not useful for the comparison. This is because only the trips with activity Shop will be analysed in this research. Therefore, the Work, Business, and Other activities were excluded, resulting in 409 responses. These responses are discussed in the following section.

4.1.1 Shop trips

According to the survey results, approximately 28% of the visitors shopping at Trefcenter Venlo were in a tour. The different tour types are presented in Figure 9. From top-down, the first three entries are visitors who were in fourth-and-back trips (i.e., pre-activity equals post-activity). As expected, most of the visitors go from home to the mall and then return home.

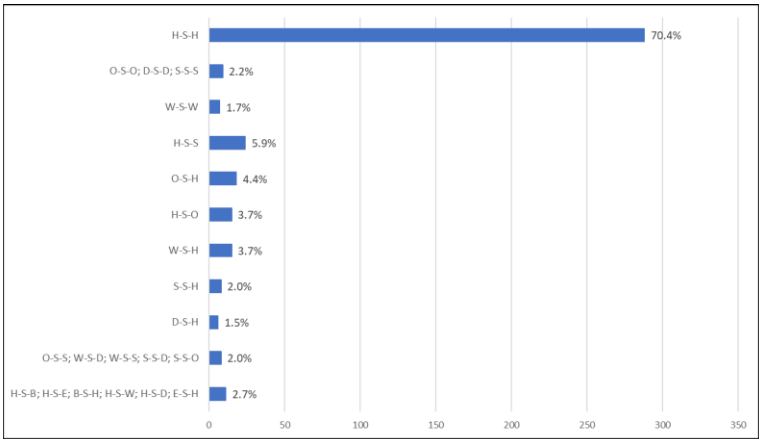

Figure 9: Tour types of visitors

The shopping trips of visitors of Trefcenter Venlo are compared in the following sub-sections. The mode shares, travel times, and distances of the trips are analysed. The results are first discussed according to the different activities. Thus, Section 4.1.1.1 presents the results of the visitors who were in a tour, and Section 4.1.1.2 discusses the results of visitors in fourth-and-back trips. Subsequently, the trips of visitors in a tour are compared to visitors in fourth-and-back trips in Section 4.1.1.3, without distinguishing the activities. Finally, the results based on different day parts are presented, even though they do not correspond to the time periods of the models.

4.1.1.1 Tour

Two analyses are made in this section with the responses of visitors who were in a tour. First, pre- and post-trips are combined in order to include activities Work and Shop in the analysis, due to their small sample sizes. Second, the pre-trips are compared to the post-trips for activities Home and Other.

1. **Combined pre- and post-trips**

Figures 10-13 show the mode shares (with number of observations) for each activity.

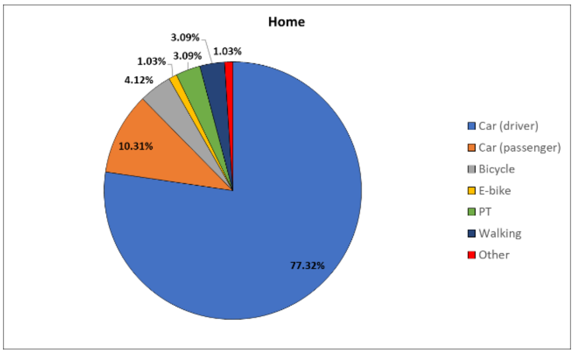

Figure 10: Modal share of Home tours (97 observations)

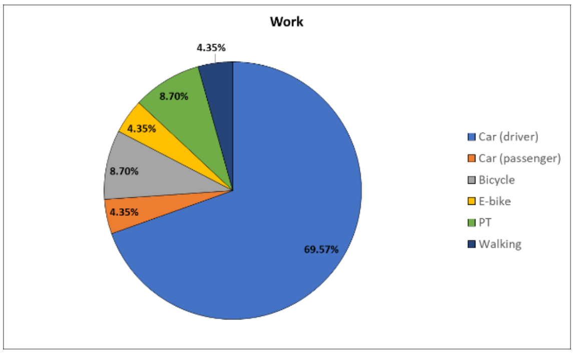

Figure 11: Modal share of Work tours (23 observations)

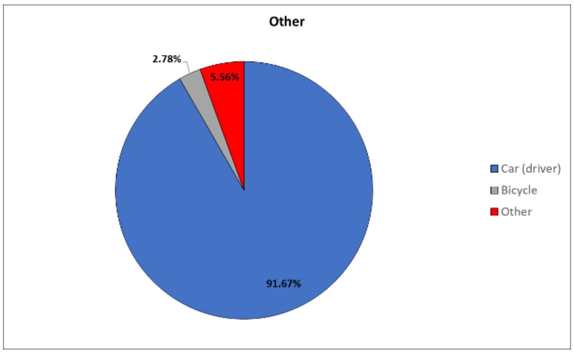

Figure 12: Modal share of Other tours (36 observations)

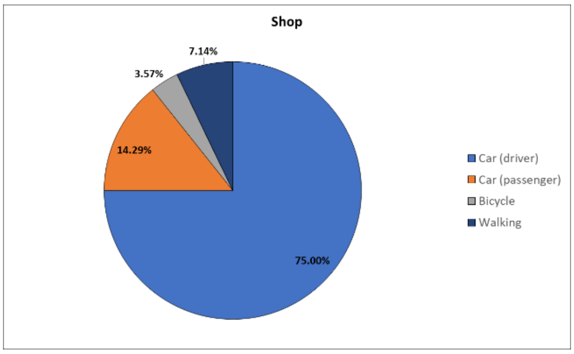

Figure 13: Modal share of Shop tours (28 observations)

Work trips of visitors in a tour has the lowest car share, but the highest percentages for (e-) bicycles and PT. This indicates that people prioritise sustainable modes for work-related tours. In addition, Work trip length is smaller than Other and Home (see Table 13), which might be due to people shopping on their way back home. The response sample shows that Work precedes Shop in approximately 83% of the work tours, suggesting that people prefer to shop after work.

Table 13: Average trip length of tours per activity

Activity	Travel time (min)	Distance (km)
Home	16.83	11.38
Other	15.13	9.13
Work	12.97	8.71
Shop	10.15	6.06

Moreover, trips of activity Other are almost always made by car. This is because people might be willing to travel longer for leisure activities (predominant in activity Other), as indicated in Table 13. Thus, car might be preferred. The number of responses is relatively balanced for Other. Other was the post-activity of 44% of the tours and pre-activity of 56%.

Furthermore, longer trips occur for activity Home. This was expected since large shopping malls attract visitors from distant places. Likewise activity Other, HB tours do not show predominance for pre- or post-trips – the mall was the last stop of approximately 52% of the tours and the first stop of 48%.

Lastly, people going from or to another shop location mostly travelled by car. This could be expected since people tend to use the car to carry things they buy, especially if they are going to different shopping locations – thus likely to carry more things. Additionally, Shop trips have the shortest travel times and distances. Since Trefcenter Venlo is located in the edge of the zone, it is possible that people go shop on a supermarket in neighbouring zones, for instance. In fact, different supermarkets can be found within 1.0 kilometre from the mall. This might also explain the unexpected high number of Shop as post-activity.

2. Pre- vs post-trips

Figures 14 and 16 show the modal share of Home and Other pre-trips. People whose first stop is the mall (48%) either go by car or active mode, probably because Shop is not their main activity in that tour. Thus, they might not want to depend on PT schedules. Moreover, Figures 15 and 17 show the modal share of Home and Other post-trips. Apart from car, the remaining modal shares are more heterogeneous in the post-trip, especially for HB trips. In addition, most of the PT trips were made by visitors which were in a tour on their way back home.

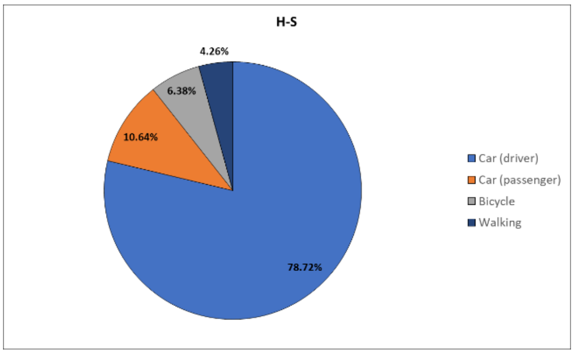

Figure 14: Modal share of H-S trips in a tour (47 observations)

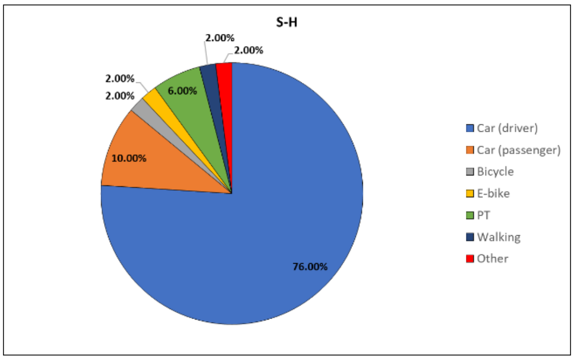

Figure 15: Modal share of S-H trips in a tour (50 observations)

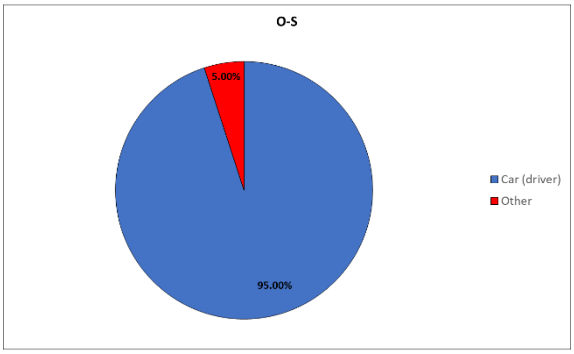

Figure 16: Modal share of O-S trips in a tour (20 observations)

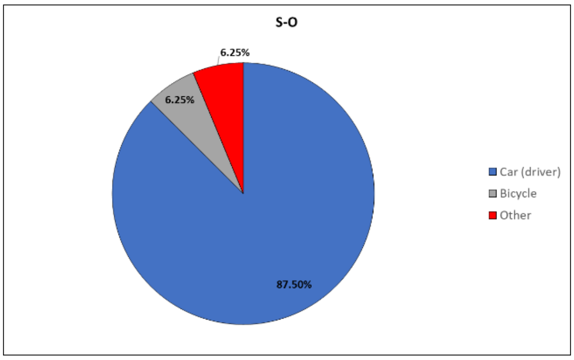

Figure 17: Modal share of S-O trips in a tour (16 observations)

Unsurprisingly, the pre-trips are longer for both activities (see Table 14). This could be explained by people coming from outside the Netherlands. Approximately 64% of them came from home, which means that they are going to somewhere else after shopping. It is very likely that their next destination was closer to the mall than their home in Germany or Belgium. Comparing the activities, again, longer trips were observed for Home.

Table 14: Average trip length of pre- and post-trips in a tour

	Travel time (min)	Distance (km)
H-S	19.03	13.25
S-H	14.73	9.63
O-S	16.38	9.29
S-O	13.59	8.94

4.1.1.2 Fourth-and-back trips

Likewise for visitors in a tour, two analyses are made with the responses of visitors in fourth-and-back trips. The first analysis combines pre- and post-trips to compare activities Home and Work. Note that activities Other and Shop were excluded here due to their small sample size. Subsequently, the second analysis compares pre- and post-trips.

1. Combined pre- and post-trips

Figures 18 and 19 show the modal shares for Home and Work activities. Higher share of active modes is observed for Work. This is due to visitors that work nearby the mall, as can be seen by the short average travel time and distance in Table 15. Thus, they can make use of healthier modes when travelling to Trefcenter during their work-time.

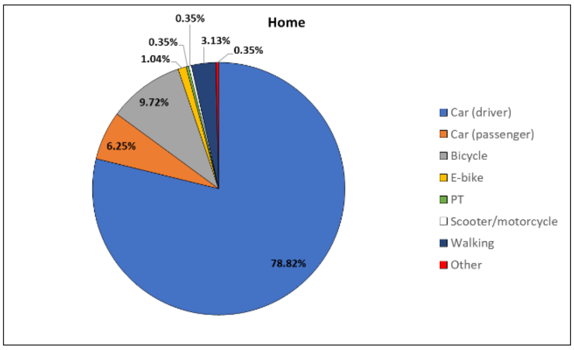

Figure 18: Modal share of H-S-H trips (288 observations)

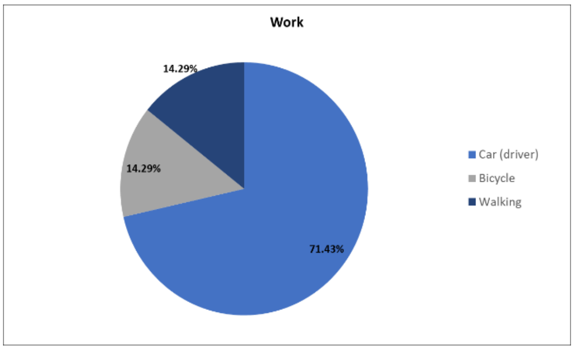

Figure 19: Modal share of W-S-W trips (14 observations)

Table 15: Average trip length of fourth-and-back Home and Work trips

	Travel time (min)	Distance (km)
H-S-H	10.42	7.03
W-S-W	5.17	3.04

Furthermore, when comparing the trip length with visitors in a tour (Table 13), the results show that fourth-and-back trips are shorter for all purposes. This was expected since people often choose to shop at closest shop facilities when not in a tour.

2. Pre- vs post-trips

The pre- and post-trips are compared for activity Home. First, the modal shares are almost identical, as shown in Figures 20 and 21. The results show that less than 1% of the visitors changed their mode of transport. Second, post-trips are shorter (see Table 16), as also observed for tours. Someone could expect that the average values were the same for fourth-and-back trips. This does not hold in the survey not only because of the differences on routes that might exist for the return trip, but also two visitors that changed their mode of transport.

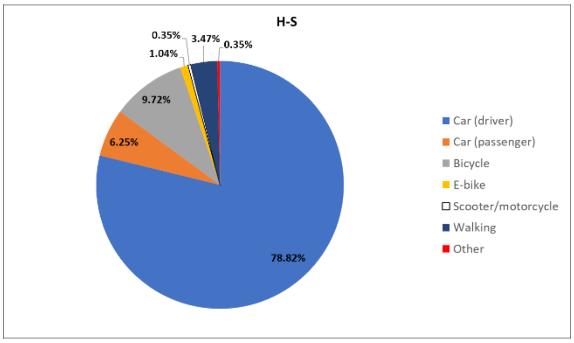

Figure 20: Modal share of fourth-and-back H-S trips (288 observations)

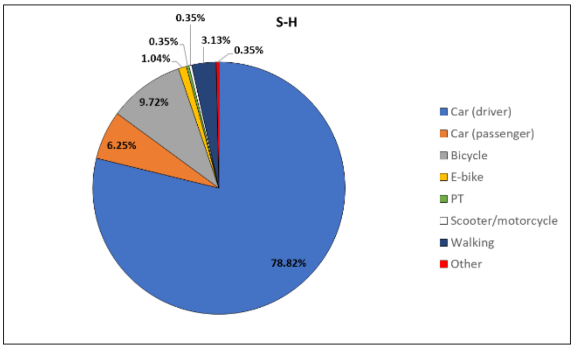

Figure 21: Modal share of fourth-and-back S-H trips (288 observations)

Table 16: Average trip length of fourth-and-back HB trips

	Travel Time (min)	Distance (km)
H-S	10.73	7.29
S-H	10.09	6.77

Furthermore, when comparing with visitors in a tour, car share is higher for tours (Figures 14 and 15). This is mainly because of car (passenger). The higher share indicates that people prefer car when in a tour, which could be expected due to the flexibility of this mode. Moreover, bikes and e-bikes were used more often by visitors who were in fourth-and-back trips. This seems logical since fourth-and-back trips are usually shorter. The overall outcomes for pre- and post-trips can be found in Figures 55-62 – Appendix F.

4.1.1.3 Overall tour vs fourth-and-back trips

The results discussed above per activity corroborate with the overall outcomes of the survey. As Figures 22 and 23 show for the combined pre- and post-trips, the lower car share and higher percentage of bicycles for fourth-and-back trips are in accordance with the results previously discussed for HB trips. This was expected since H-S-H represent most of the responses. It is interesting to mention that 25% of the HB trips were part of a tour, exactly the same share observed by Milthorpe & Daly (2010) in Australia.

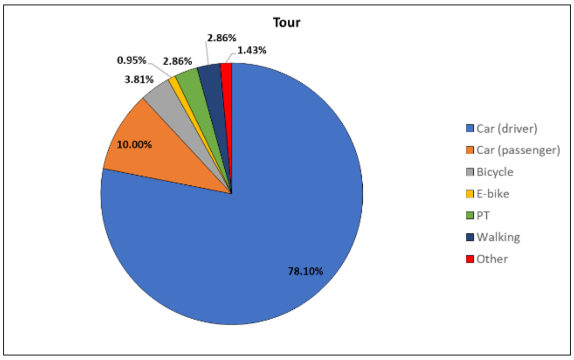

Figure 22: Modal share of tour trips (210 observations)

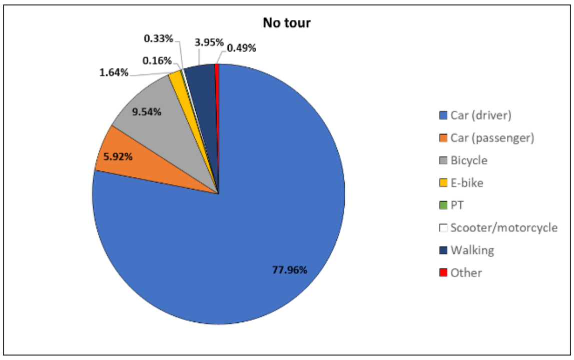

Figure 23: Modal share of fourth-and-back trips (608 observations)

Furthermore, longer travel times and distances for tours are also observed when aggregating all activities (see Table 17). People tend to combine activities to optimise their schedules during the day. Thus, they often shop on their way back home (e.g., W-S-H, O-S-H), or even before going somewhere else (e.g., H-S-O, H-S-W). These tours are usually longer, as indicated by the survey. Moreover, when comparing pre- and post-trips, the pattern of the activity analysis repeats, with longer pre-trips. The travel time and distance distributions can be found in Figures 63-70 – Appendix F.

Table 17: Average trip length of visitors

	Tour	**No tour**
	Travel time (min)	
Pre-trip	16.28	10.65
Post-trip	12.66	9.91
	Distance (km)	
Pre-trip	11.05	7.13
Post-trip	7.94	6.60

4.1.1.4 Day part trips

The company responsible for conducting the survey did not provide the exact time of the responses. Rather, they were divided in three periods, which are (called here) the morning (09:00 to 12:00), afternoon (12:00 to 15:00), and evening (15:00 to 18:00). Although they are not equivalent to the time periods in the models – thus not useful for the comparison, an analysis of the day parts can still be made. For the 409 responses of visitors who were shopping at the mall, about 29% were obtained in the morning, 44% in the afternoon and 28% in the evening. Table 18 shows the share of tours for each day part. For this analysis, it is assumed that people travelled to and from the mall at the same day period they responded the survey.

Table 18: Share of tours per day part

Day part	**Tour**	**Fourth-and-back**
Morning	18.6%	81.4%
Afternoon	28.1%	71.9%
Evening	29.3%	70.8%

When looking at the day parts separately, the portion of tours in the morning is lower than in the rest of the day. This was expected since combining activities during the day can take a considerable time. Thus, unless the mall is the first stop, it is likely that the Shop activity will happen later in the day. The survey confirms that since Trefcenter was the first stop of 55% of the morning tours, 47% of the afternoon, and 35% of the evening tours. Further, interestingly, the afternoon and evening shares in Table 18 are similar. Higher share of tour was expected for the evening because of the peak hours (between 16:00 and 18:30 (NS, n.d.)), where many people return home from work (and possibly make a stop at Trefcenter). Extending the survey to encompass the whole evening peak, e.g., until 18:30, would likely lead to a higher share of tours in the evening.

Furthermore, the modal share of the combined pre- and post-trips per day part is also analysed (see Figures 24-26). The morning and afternoon trips show higher share of bicycle. One possible reason is the fact that the evening period partially encompasses the evening peak. In contrast, the morning peak hours in the Netherlands (between 06:30 and 09:00) are not covered by the survey. Thus, some cyclists might prefer to shop in less busy times to reduce their exposure to congestion, pollution, and crash risks. Moreover, the car (passenger) share is higher in the evening period. It is more likely that people from the same household combine their trip to the mall in the end of the day, after concluding their work or study activities. Also, this could be due to parents driving their kids after picking them up at school or somewhere else – almost 30% of the evening car (passenger) came either from Education or Delivery stop.

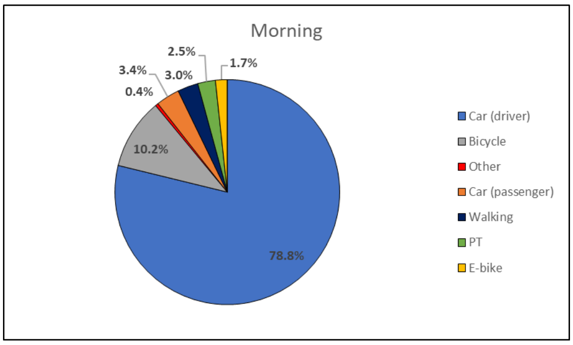

Figure 24: Modal share of morning responses (236 observations)

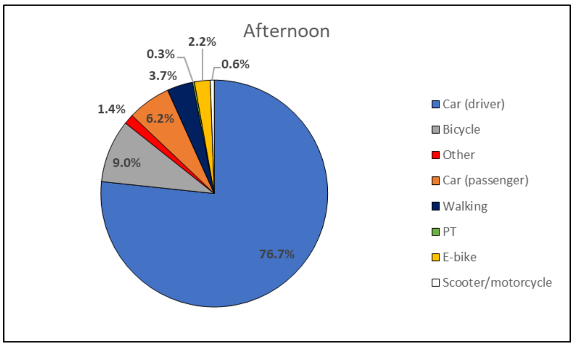

Figure 25: Modal share of afternoon responses (356 observations)

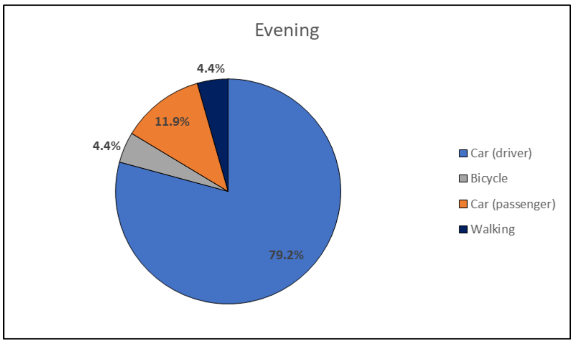

Figure 26: Modal share of evening responses (226 observations)

4.2 Models' results

This section presents and compares the overall differences between the model results. This is done for the Trip Generation, Trip Distribution, and Modal Split steps. In addition, the necessary adjustments made to fine-tune the trip-based model are also explained.

4.2.1 Trip Generation

Despite the different purposes in the two models discussed in Section 3.3.2.3.1, the TBM has a feature that enables a comparison of the trips produced and attracted according to the trip-based model purposes. To recall, the generation in the TBM is a result of the personas and tour frequencies (see Section 3.3.2.2.1). The total trips generated by the trip-based model was significantly higher than the TBM in the first runs (see Table 54 – Appendix G). This is mainly due to the high differences for purposes Business and Other. These differences are possibly due to the extra socio-economic attributes used in the trip-based model (see Tables 51 and 52 – Appendix D). Unfortunately, this could not be fixed. Thus, to reduce the gap, both the production and attraction coefficients of purposes Business and Other of the trip-based model were scaled down to match the TBM trips. This was done by multiplying them by factors, which are 0.36 for Business and 0.63 for Other. These factors were calculated according to Equation 17.

$$factor = \frac{2 * Trips_{TBM}}{Prod_{trip-based} + Attr_{trip-based}} \quad (17)$$

The final results of the Trip Generation can be seen in Table 19. The trip-based model trips correspond to the results before balancing departure and arrival. The TBM results are already balanced. However, they do not correspond to the trip generation of that model. The TBM generation consists of the total number of people willing to travel, but not all of them depart from the zones. Thus, the TBM trips shown in Table 19 correspond to the actual departures and arrivals, which is indeed what is comparable to the trip-based model trips. For this reason, from now on, the trips produced and attracted by the trip-based model are also referred to as departures and arrivals.

Table 19: Trip generation results

Purpose	TBM	Trip-based model	
		Departure	Arrival
Home-Work	55,829,594	64,177,567	59,466,710
Home-Shop	31,670,959	30,117,128	39,394,302
Home-Education	19,930,161	12,671,625	20,794,993
Home-Business	2,411,088	4,732,587	3,589,000
Business	3,733,722	3,733,722	3,733,722
Other	114,260,802	114,588,569	113,933,035
Work-Home	50,099,413	55,600,052	45,838,907
Shop-Home	34,393,400	31,526,142	36,339,022
Education-Home	17,741,032	15,800,502	19,962,301
Business-Home	3,269,447	2,746,009	2,058,947
Total	**333,339,617**	**335,693,902**	**345,110,939**

It is important to discuss the main differences between the trip generation of the models. First, the Home-Education departures of the trip-based model are significantly smaller than the TBM (more than 35%). However, the departures in the trip-based model are determined only by the number of inhabitants of the zones (see Table 51 – Appendix D). Thus, no improvement could be made. Second, despite the adjustments in the coefficients of part-time workers (see Section 3.3.2.3.2), the trip-based model still generates considerably more trips of purposes Home-Work and Home-Business. Likewise Home-Education, no improvement could be made for H-W and H-B.

Furthermore, it is also important to analyse the trips of opposing purposes (e.g., H-W vs W-H) in the trip-based model, as they should be compatible. Unfortunately, large differences can be observed since the departures and arrivals were determined based on different OViN data. First, the departures of purposes with destination Home (i.e., W-H, S-H, E-H, and B-H) and the arrivals of purposes with origin Home (i.e., H-W, H-S, H-E, and H-B) are compared. The number of arrival trips are considerably higher, mainly for H-S and H-E. To recall, the attractions of the trip-based model use the coefficients from the TBM. Thus, the higher arrivals might be justified by the destination activity in the TBM, which includes more trips than only from Home. For example, activity Work in the TBM contains not only H-W trips, but also E-W, S-W, etc.

Nevertheless, the trips are balanced to the Home side. Thus, the departures of purposes with origin Home and the arrivals of purposes with destination Home should be analysed. These trips largely differ because they are based on different socio-economic data (see Table 51 – Appendix D). This could have been further fine-tuned but was not done due to time limitations. Therefore, those differences are propagated to the subsequent steps of the trip-based model. However, this issue is not expected to significantly affect the comparison performed in this research since the Shop (and other) trips were further fine-tuned in the distribution step, as explained in the following section.

4.2.2 Trip Distribution

The Trip Distribution outcomes are investigated for different zones. For this purpose, three groups of zones were defined according to their area, as presented in Table 20. This was done in order to evaluate the effects of the adjustments in the trip-based model while developing it, which is expected to affect the behaviour of the trips differently depending on the size of the zones.

Table 20: Zone groups

Group	Zone	Area [ha]	Area type – urban degree
Small zones	Trefcenter Venlo	395.8	Study area (NL) - 5
	Maastricht Centrum	13.7	Study area (NL) - 1
	Roermond Centrum	43.6	Study area (NL) - 1
	Aachen Centrum	26.4	Study area (DE) - 1
Middle-sized zones	Amsterdam	51,754.3	Outside area (NL) - 3
	Utrecht	53,452.5	Outside area (NL) - 3
	Deventer	41,903.4	Outside area (NL) - 3
Large zones	France 1	35,740,648.7	Outside area (BE) - 3
	Frankfurt	1,604,376.0	Outside area (DE) - 3
	Berlin	5,161,061.4	Outside area (DE) - 3

The first group consists of small zones in the study area, as shown in Figure 27. They include two zones in Limburg and a zone in Germany, near the border. The Trefcenter zone focussed on this research is also included in this group. Although larger than the others, similar behaviours of the models are expected to this zone due to its location inside the study area.

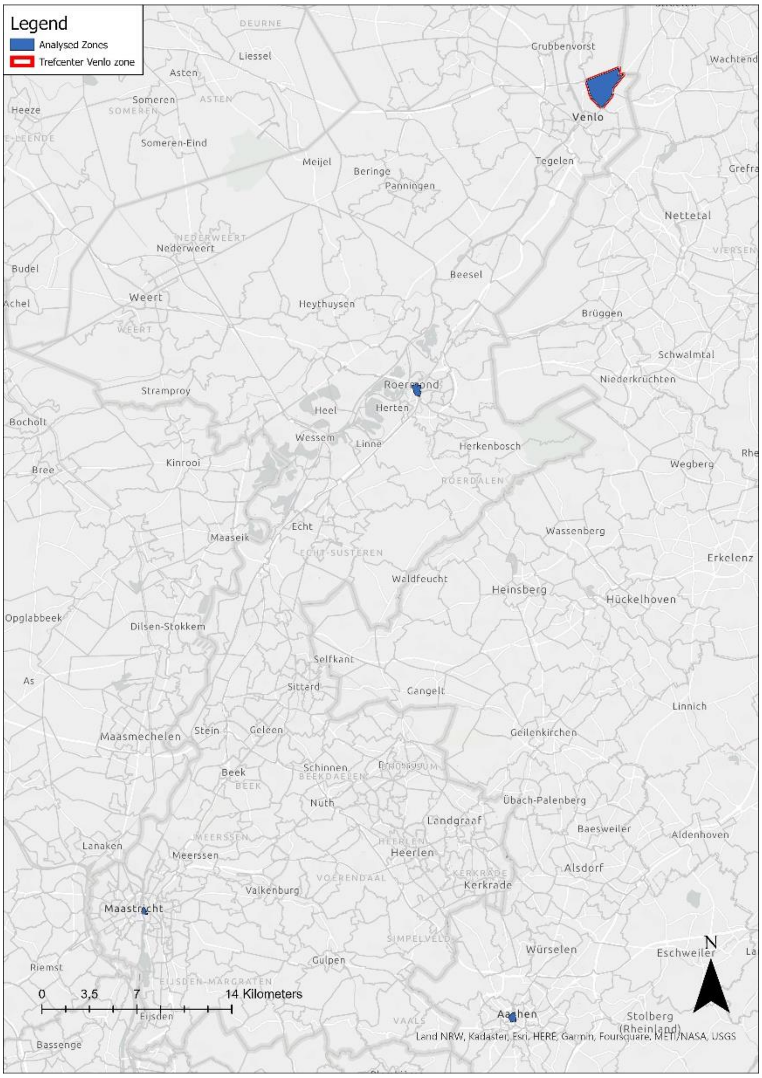

Figure 27: Small analysed zones in study area

The second group contains "middle-sized" Dutch zones. They correspond to the cities of Utrecht, Amsterdam, and Deventer. They were selected based on different position throughout the country and in relation to the study area in Limburg. Finally, the third group consists of large zones. They are two zones located in Germany and one in France. The middle-sized and large zones can be seen in Figure 28.

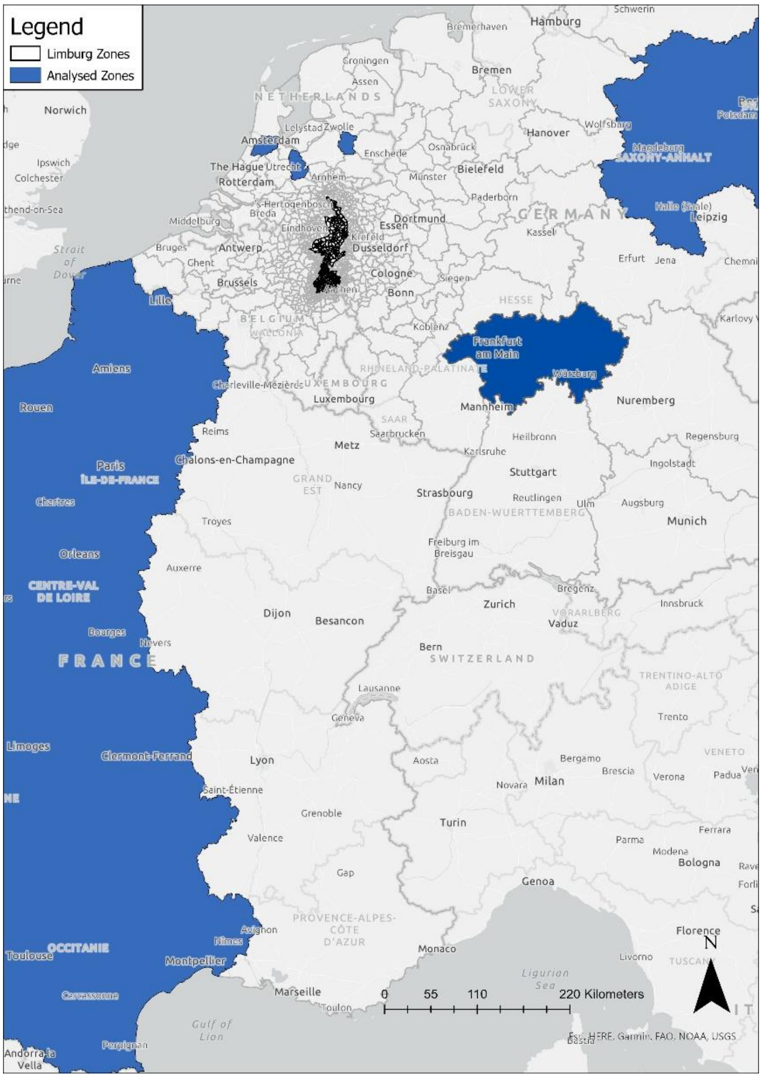

Figure 28: Middle-sized and large analysed zones

The first run of the Trip Distribution of the trip-based model generated a large amount of non-intrazonal trips for large zones. Tens of millions of trips produced or attracted by those zones are certainly unrealistic. As a comparison, the TBM generates less than 11 million non-intrazonal trips in the whole model. This indicates a limitation of the trip-based model to deal with large zones. Therefore, intrazonal trips were not calculated in the trip-based model. It is important to mention that this is a common practice for the models developed by RHDHV. Also, it is at first not a problem since intrazonal trips are not assigned to the network. Nevertheless, the intrazonal trips are removed based on the area of the zone. More specifically, they are subtracted from the departures and arrivals as follows. The share of non-intrazonal trips is calculated as in Equations 18 and 19. For each zone, that factor is multiplied by the total departure and arrival per purpose, resulting in the number of trips to be distributed to all other zones. A new balancing occurs after updating the trips generated.

$$factor^{i}_{non-intrazonal} = 1 - \min\left[\left(\frac{1}{\alpha * e^{(\beta * r_i)}}\right), 0.9998\right] \tag{18}$$

$$r_i = \frac{\sqrt[2]{\frac{A_i}{\pi}}}{100} \tag{19}$$

Where:

A_i = area of zone i.

The alpha and beta coefficients were refined based on the intrazonal trips of the TBM. In other words, they were adjusted such that the percentages of intrazonal trips did not deviate significantly from the TBM. These coefficients are shown in Table 55 – Appendix G. Moreover, not only the total trips of the whole model were compared (see Table 21), but also the share of intrazonal trips in the different zone groups. For this purpose, one zone of each group was investigated, which are Trefcenter Venlo, Utrecht and France 1. The resulting share of intrazonal trips can be seen in Table 22.

Table 21: Total and non-intrazonal trips per purpose

Purpose	TBM		Trip-based model	
	Total	Non-intrazonal	Total	Non-intrazonal
Home-Work	55,829,594	2,129,853	64,177,567	1,863,711
Work-Home	50,099,413	1,871,793	45,838,907	1,425,032
Home-Shop	31,670,959	646,986	30,117,128	676,311
Shop-Home	34,393,400	764,216	36,339,022	890,953
Home-Education	19,930,161	752,393	12,671,625	440,039
Education-Home	17,741,032	676,178	19,962,301	690,960
Business	3,733,722	158,476	3,733,722	153,504
Home-Business	2,411,088	137,589	4,732,587	184,531
Business-Home	3,269,447	182,079	2,058,947	87,464
Other	114,260,802	3,211,823	114,260,802	3,568,323
Total	**333,339,617**	**10,531,386**	**333,892,607**	**9,980,829**

Table 22: Share of intrazonal trips of analysed zones

Zone	Total trips		Intrazonal trips	
	TBM	Trip-based	TBM	Trip-based
Trefcenter Venlo	15,852	16,526	7.08%	10.70%
Utrecht	812,753	751,968	94.18%	98.40%
France 1	82,457,477	80,676,696	99.91%	99.96%

4.2.2.1 Distribution results

The Trip Distribution results are discussed in this section. Only the non-intrazonal trips are analysed since there are no intrazonal trips in the trip-based model. Table 23 presents the non-intrazonal trips of the groups of zones. The trips per purpose can be found in Tables 56-65 – Appendix G.

Table 23: Non-intrazonal trips of analysed zones

Zone	**TBM**		**Trip-based model**	
	Departure	**Arrival**	**Departure**	**Arrival**
Trefcenter Venlo	7,364	7,364	7,046	7,711
Maastricht Centrum	3,153	3,153	3,975	3,374
Roermond Centrum	6,485	6,485	10,291	8,809
Aachen Centrum	6,624	6,624	7,437	6,339
Utrecht	23,639	23,639	6,012	6,051
Amsterdam	67,290	67,290	23,086	23,026
Deventer	9,092	9,092	4,497	4,579
France 1	37,832	37,832	15,384	16,449
Frankfurt	18,501	18,501	2,204	2,057
Berlin	8,351	8,351	3,250	3,059

Both the middle-sized and large zones generate significantly less trips in the trip-based model. This is a result of the intrazonal trips exclusion in that model. First, for middle-sized zones, this could be improved by further adjusting the alphas and beta coefficients of Equation 18. However, this was not done since such improvement could hinder the distribution in the study area, including Trefcenter Venlo which is the focus of this research. Second, for large zones, the non-intrazonal factor (Equation 18) is limited by the threshold 0.9998. This means that sufficiently large zones necessarily have 0.02% of their trips distributed externally (i.e., to other zones). An increase in this value was attempted by changing the threshold to 0.9995. However, it failed due to errors in the model runs, which could not be solved on time for this research. Additionally, trips of all purposes are generated in the trip-based model of large zones (see Tables 63-65 – Appendix G). This is not realistic since nobody living in those zones works or studies outside them. Again, the threshold 0.9998 leads to the same factor for all purposes in large zones (i.e., 0.02%), which means that there will be non-intrazonal trips in large zones for every purpose. Nevertheless, those issues might not significantly influence in Trefcenter Venlo zone, hence not affecting the comparison with the survey.

Moreover, the departures and arrivals are more balanced in the trip-based model of middle-sized and large zones. The gaps between the trips generated per purpose (i.e., absolute value of departures minus arrivals) are significantly higher in the TBM, as illustrated in Table 24 for Utrecht and Berlin zones. Thus, the departures and arrivals of the trip-based model seem to be restricted.

Table 24: Gap between trips produced and attracted of middle-sized and large zones

Purpose	**Utrecht**		**Berlin**	
	TBM	**Trip-based**	**TBM**	**Trip-based**
Home-Work	54%	0.2%	105%	10%
Work-Home	35%	12%	51%	11%
Home-Shop	151%	10%	-	17%
Shop-Home	52%	18%	100%	5%
Home-Education	49%	4%	632%	19%
Education-Home	32%	32%	81%	12%
Business	11%	0%	100%	0%
Home-Business	0.1%	1%	3050%	15%
Business-Home	4%	15%	67%	18%
Other	2%	1%	0.1%	0.4%

Indeed, including intrazonal trips in the trip-based model "allowed" for larger gaps per purpose in Utrecht, as illustrated in Table 66 – Appendix G. This is again due to the removal of intrazonal trips which negatively affect the model by creating a constraint in it. That is, it makes the share of non-intrazonal trips equal for both the trips departing and arriving at each zone – at least before re-balancing. When this constraint does not exist (i.e., intrazonal trips are calculated), the distribution is "free" to have different non-intrazonal percentages for departures and arrivals. This difference is expected to be high for some purposes. For example, consider purpose Shop-Home in Utrecht zone. Utrecht is a commercial hub in the Netherlands, with many shopping facilities. Thus, many S-H trips produced by Utrecht are expected to be non-intrazonal since many people living outside the city shop in Utrecht. On the other hand, most of the S-H trips attracted to Utrecht are expected to be intrazonal. This is simply because not many people living in Utrecht might go shop in other zones. Therefore, the percentage of non-intrazonal S-H trips produced by Utrecht should be higher than the percentage of trips attracted to the zone. The TBM reflects it, as can be seen in Table 25. Note that the small difference in the trip-based model (without intrazonal trips) is after balancing the zones' trips. The non-intrazonal share before balancing is the same. Therefore, the exclusion of intrazonal trips hindered the trip-based model in this research.

Table 25: Non-intrazonal share of purpose Shop-Home in Utrecht zone

Model	Departure	Arrival
TBM	1.10%	0.53%
Trip-based (without intrazonal trips)	0.56%	0.51%
Trip-based (with intrazonal trips)	15.20%	4.92%

Moreover, the effects of the aforementioned constraint can be observed in the different zone groups, and they relate to the size of the zones. The higher the non-intrazonal factor, the higher the gap between departures and arrivals per purpose. This means that higher gaps can be observed in small zones – which have higher factors. This seems to give more "flexibility" to the departures and arrivals of those zones, which is closer to reality. Therefore, the mall's trips are not significantly hindered by the exclusion of the intrazonal trips. To illustrate, Table 26 shows the gaps in Trefcenter Venlo zone.

Table 26: Gap between departures and arrivals of Trefcenter Venlo zone

Purpose	TBM	Trip-based
Home-Work	469%	469%
Work-Home	82%	81%
Home-Shop	2617%	1419%
Shop-Home	96%	91%
Home-Education	34%	9%
Education-Home	52%	8%
Business	3%	0%
Home-Business	328%	455%
Business-Home	77%	75%
Other	7%	7%

Furthermore, another difference between the models observed on the distribution results relates to the balancing of trips. The TBM departure and arrival trips are balanced on each zone. This makes sense since the tours always start and finish at home, thus all trips that go out of a zone will return to that zone. The trip-based model does not link the trips, and the total departures and arrivals can differ. This leads to inconsistencies in the model since a trip going out of a zone does not necessarily return to the same zone, as already detected by other authors (Davidson et al., 2007; Vovsha, 2019). Rather, it can go to another zone.

Finally, by comparing the trip distribution of the models, it is possible to conclude that, although common practice, the exclusion of intrazonal trips from the trip-based model is an important limitation of this research, especially for middle-sized and large zones. On the other hand, including it resulted in unrealistic amount of non-intrazonal trips in large zones, as already mentioned. Thus, further investigation on the calculation of intrazonal trips according to the area of the zones is suggested. Nonetheless, the Trefcenter and other small zones in the study area are not significantly affected by the removal of intrazonal trips. Hence, the comparison of Shop trips with the survey can still be made.

4.2.3 Modal Split

Likewise in the Trip Distribution, the Modal Split results are also investigated for the different zone groups. This is first done for the total trips of the zones. Subsequently, the modal split is analysed per purpose.

4.2.3.1 Modal split of zone groups

The modal split varies when analysing the departures and arrivals separately in the trip-based model. The fact that the trips of the TBM are balanced in every zone leads to the same modal split for departures and arrivals in this model. This was expected since it is not possible to change modes within a tour. However, by not interlinking trips, the mode of the outward trip can be different than the return trip in the trip-based model. This is indeed observed in the modal share of small zones, as shown in Table 27, corroborating with Davidson et al. (2007). The results of the remaining zones can be found in Table 67 – Appendix G, as they do not differ significantly.

Table 27: Modal split of departures and arrivals of trip-based model of small zones

Zone	Departure			Arrival		
	Car	Bicycle	PT	Car	Bicycle	PT
Trefcenter Venlo	63%	32%	5%	64%	29%	7%
Maastricht Centrum	55%	37%	8%	42%	48%	10%
Roermond Centrum	67%	22%	11%	50%	40%	10%
Aachen Centrum	78%	14%	8%	74%	19%	7%

Large differences can be observed in the modal split of Maastricht Centrum and Roermond Centrum zones, especially for car and bicycle. This may be due to the location of these zones, which is in the city centre. Parking costs are higher in those zones, hence car is less attractive for people traveling to them. Those trips seem to be switched to bicycle, as PT shares do not differ significantly. This behaviour is not observed in Trefcenter zone, which is in the outskirts of Venlo where parking costs are zero. Moreover, although also in the city centre, Aachen Centrum zone does not have parking cost either and the difference in car share is smaller. Thus, this difference is probably due to different route costs.

Furthermore, it is also interesting to analyse the combined modal split, consisting of the sum of the departures and arrivals of each zone. These modal shares are shown in Table 28.

Table 28: Modal split of the analysed zones

Zone	TBM			Trip-based model		
	Car	Bicycle	PT	Car	Bicycle	PT
Trefcenter Venlo	74%	21%	5%	64%	30%	6%
Maastricht Centrum	46%	45%	9%	49%	42%	9%
Aachen Centrum	71%	20%	9%	76%	16%	8%
Roermond Centrum	57%	32%	12%	59%	31%	11%
Utrecht	72%	0%	28%	82%	1%	18%
Amsterdam	66%	0%	34%	84%	1%	15%
Deventer	72%	0%	28%	85%	0%	15%
France 1	88%	0%	12%	90%	0%	10%
Frankfurt	62%	0%	38%	85%	0%	15%
Berlin	85%	0%	15%	85%	0%	15%

Bike and car shares considerably differ in Trefcenter Venlo zone. In addition, large differences are observed for middle-sized zones and Frankfurt, where car is significantly more attractive and PT share is considerably lower in the trip-based model. To understand the reasons of those differences, it is important to look at the modal split per purpose, as discussed in the following section.

4.2.3.2 Modal Split per purpose

The analysis of the modal split per purpose is discussed in this section focussing on the small zones. It helps to identify not only potential issues in the development of the trip-based model, but also patterns in the distribution of trips by the two approaches. Purposes which the modal shares differ the most between the models are discussed. Table 29 illustrates the modal split per purpose for Trefcenter zone. The results of the remaining zones can be found in Tables 68-76 – Appendix G.

Table 29: Modal split per purpose of Trefcenter Venlo zone

Purpose	TBM			Trip-based model		
	Car	Bicycle	PT	Car	Bicycle	PT
Home-Work	75%	20%	6%	52%	37%	11%
Work-Home	75%	19%	6%	53%	38%	9%
Home-Shop	78%	17%	4%	72%	25%	3%
Shop-Home	77%	18%	5%	73%	24%	3%
Home-Education	18%	69%	13%	63%	34%	3%
Education-Home	18%	68%	14%	46%	51%	3%
Business	77%	19%	4%	90%	7%	3%
Home-Business	91%	5%	3%	91%	6%	3%
Business-Home	88%	9%	3%	88%	10%	3%
Other	73%	22%	4%	64%	30%	6%

First, the Education purposes are hindered everywhere, as car share is considerably higher in the trip-based model. This is not expected since most students do not drive, and if they are taken by someone else to school, this trip would be a Delivery activity (inside Other purpose in trip-based model). Therefore, a small share of car trips seems more realistic, as shown by the TBM. This model distinguishes age groups in the personas. Since most students are children and teenagers, it takes into consideration that they do not drive (car deterrence functions are null for people under 18 years old). Therefore, the TBM does not assign car trips to or from school for those personas. On the other hand, the trip-based model is not able to distinguish people characteristics. In addition, the car distribution functions used in the model seems to represent only adult trips, which is a drawback of the trip-based model that could not be solved on time for this research.

Second, the shares of Work purposes also deviate from one model to the other in small and middle-sized zones. Car share is lower, while bicycle and PT shares are higher in the trip-based model. To investigate it, it is important to first look at the number of trips per model. In this regard, the W-H trips produced by Trefcenter Venlo zone are analysed. The trip-based model produces 5% more W-H trips than the TBM, which is not sufficient to justify the modal share differences. Therefore, the zones where the trips were assigned to are also analysed, as can be seen in Figures 29 and 30. The workers of Trefcenter Venlo zone live closer according to the trip-based model, despite the German zones. Therefore, more W-H trips are made by bike and PT, as shown in Table 29.

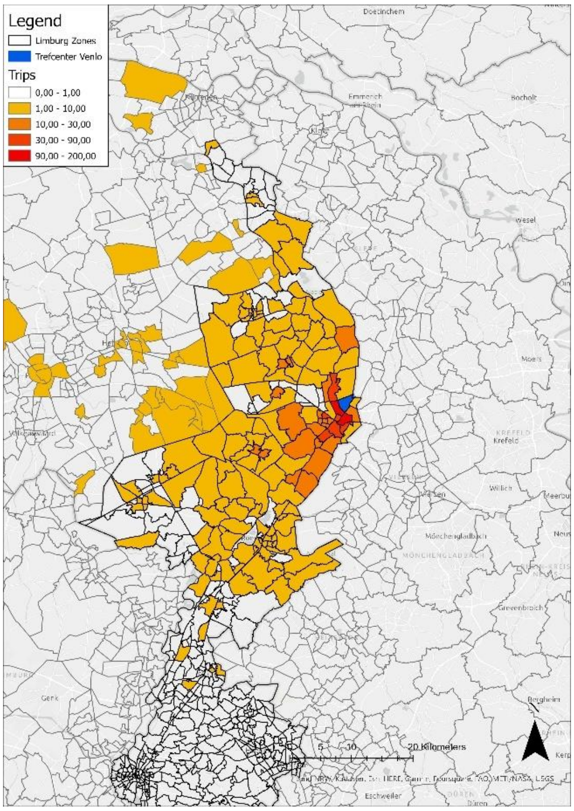

Figure 29: W-H trips from Trefcenter zone of TBM

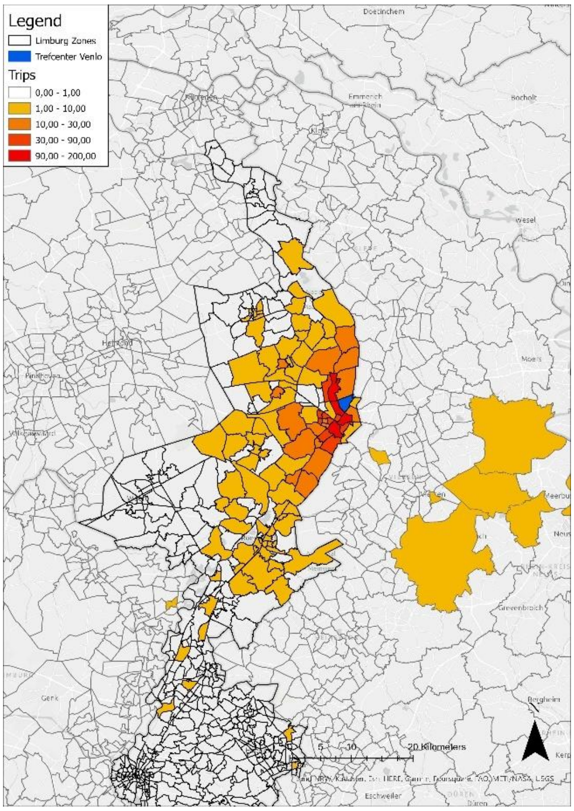

Figure 30: W-H trips from Trefcenter zone of trip-based model

Third, bike share is considerably higher for purpose Business in small zones of the TBM. Again, the trips departing from Trefcenter zone are investigated. The number of trips in the trip-based model is 26% higher than the TBM. Also, the TBM distributes trips to closer zones – see Figures 31 and 32. Therefore, it is not possible to conclude whether bicycle is more attractive in the TBM due to less departures or because the model distributes it to closer zones.

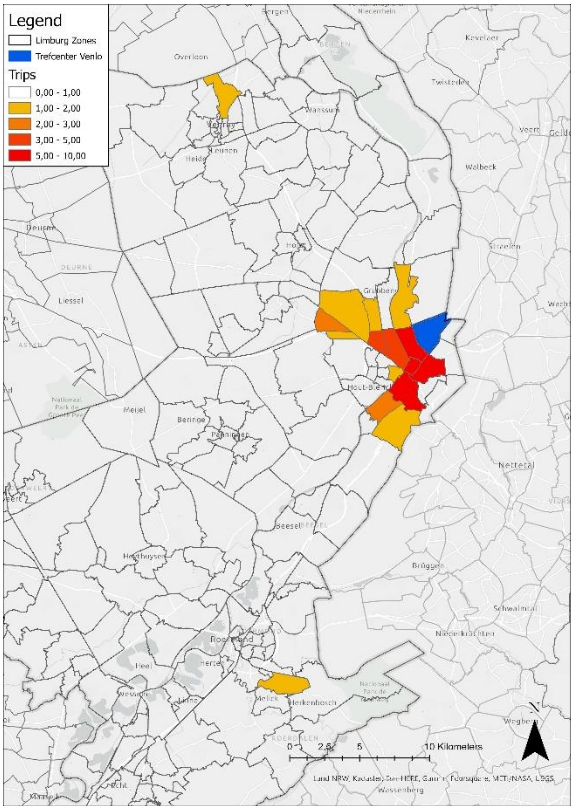

Figure 31: Business trips from Trefcenter zone of TBM

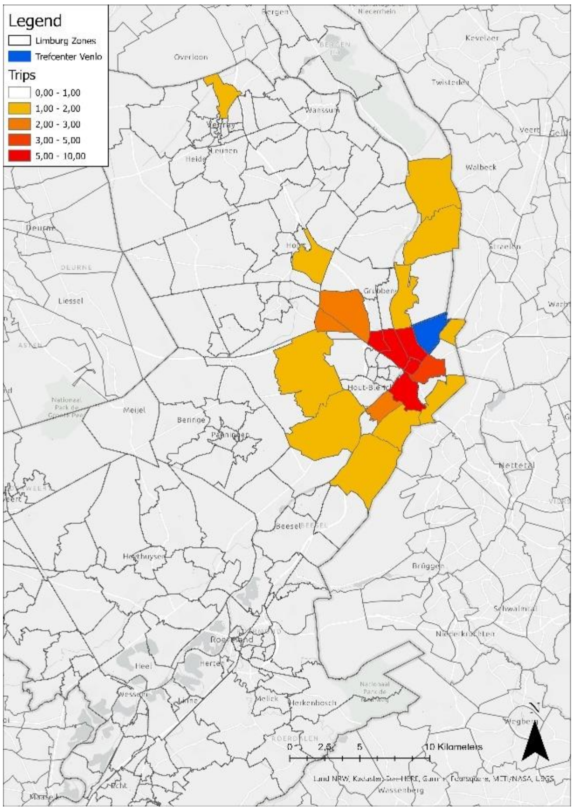

Figure 32: Business trips from Trefcenter zone of trip-based model

Fourth, the shares of Shop purposes also differ for Roermond and Maastricht. Car share is considerably higher for purpose S-H in those zones of the trip-based model, as shown in Table 30. This is likely due to the large difference in number of trips generated (departure + arrival), which is significantly higher in the trip-based model (see Tables 57 and 58 – Appendix G). For this reason, the model distributes trips to farther destinations, as illustrated in Figures 33 and 34 for S-H trips departing from Maastricht. Similar behaviour happens in Roermond Centrum.

Table 30: Shop-Home modal share

Purpose	**TBM**			**Trip-based model**		
	Car	**Bicycle**	**PT**	**Car**	**Bicycle**	**PT**
Maastricht Centrum	31%	60%	9%	65%	31%	4%
Roermond Centrum	44%	47%	9%	72%	18%	9%

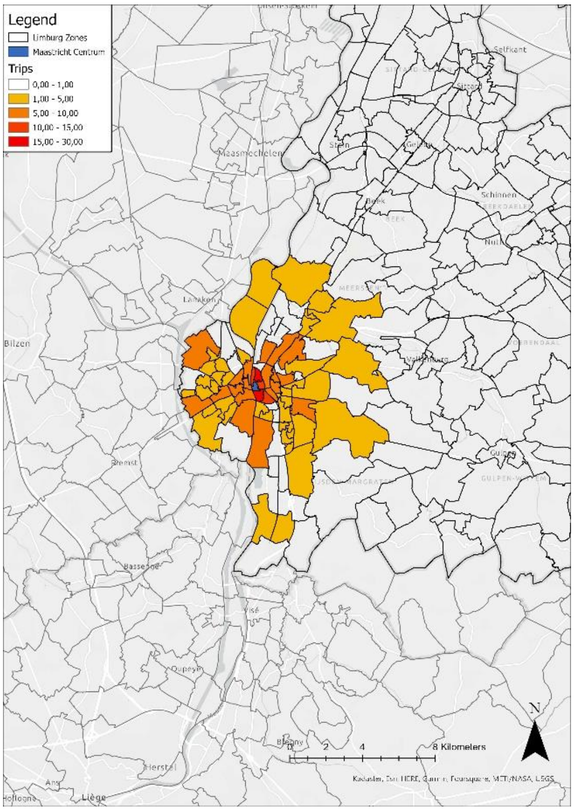

Figure 33: S-H trips from Maastricht Centrum of TBM

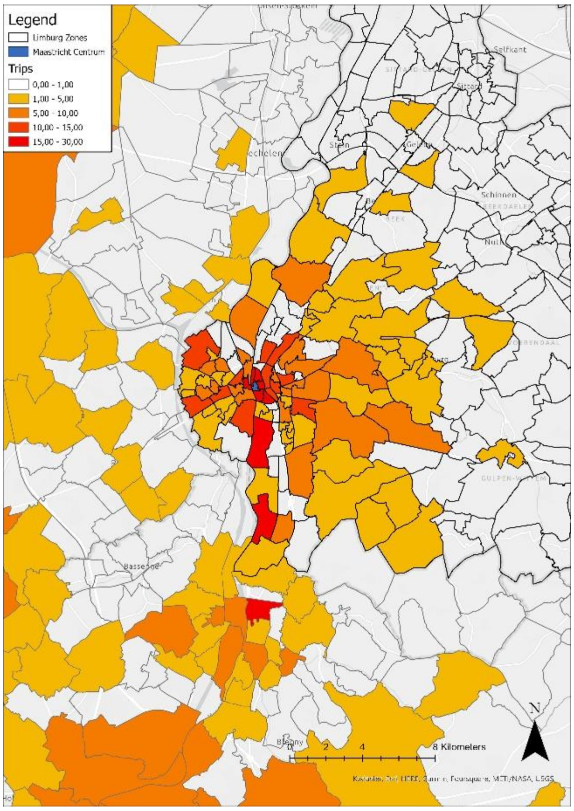

Figure 34: S-H trips from Maastricht Centrum of trip-based model

Last, the modal shares of purpose Other in the small zones also differ. As already mentioned, this purpose is an issue in the trip-based model due to the aggregation of NHB trips. In the trip-based model, 36% of all non-intrazonal trips are of this purpose – confirming the increase in NHB trips stated by Bernadin & Chen (2018), which stress the complexity of estimating them.

To conclude, purposes Other, Home-Education and Education-Home are problematic in the trip-based model developed by this research. Despite them, the other large differences in the modal split per purpose are apparently due to either the distribution method (W-H purpose) or the differences in the number of trips (S-H purpose). Therefore, no clear conclusions can be drawn yet regarding how the models distribute the trips to the zones.

4.3 Comparison of models

This section presents the comparison of the models with the real observations. First, the modal split, trip length, and home location of the H-S and S-H trips are compared to the survey results. Subsequently, the trips assigned by the models to the network are compared to traffic counts.

4.3.1 Comparison with survey

1. **Modal Split**

To be comparable to the models, the modal shares of the survey should be filtered. Thus, only car (driver), bicycle (plus e-bike and scooter/motorcycle), and PT shares are considered. The purposes that are relevant for the comparison of the models with the survey are Home-Shop (pre-trip) and Shop-Home (post-trip). The modal split of the models and the survey can be seen in Table 31. It is important to mention that the intrazonal trips were also removed from the survey. For this purpose, the responses of visitors that live on PC4 5916 were excluded (39 responses). This PC4 corresponds exactly to the zone in the models.

Table 31: Modal split of models and survey

	TBM			Trip-based model			Survey		
	Car	Bicycle	PT	Car	Bicycle	PT	Car	Bicycle	PT
Home-Shop	78%	17%	5%	73%	23%	4%	90%	10%	0%
Shop-Home	78%	17%	5%	74%	23%	3%	89%	10%	1%

None of the models perform well, as both underestimate car trips and overestimate bicycle and PT trips. As already mentioned, Trefcenter Venlo is near the motorway A67. This facilitates car trips, as observed in the survey. However, the Shop distribution functions derived from OViN encompass different shopping facilities, not distinguishing their characteristics. This function might be overestimated for bike and PT, which would explain the differences to the survey for both models.

Additionally, the trip-based model performs poorly even when comparing it with visitors making fourth-and-back trips in the survey. The responses of the visitors showed that 88% of the H-S fourth-and-back trips were made by car and 12% by bicycle. Also, 87.7% of the S-H fourth-and-back trips were made by car, 11.9% by bike, and 0.4% by PT.

Finally, Table 32 shows the average RSE of the modal split. The TBM performs better than the trip-based model for both the pre- and post-trips.

Table 32: Average RSE in percentage points (p.p.) of modal split

	TBM	Trip-based
H-S	7.6	10.6
S-H	7.2	9.4

2. Trip length

The travel time and distance results are presented in this section. Both the trip frequency distributions and average trip length are compared. It is important to mention that the trip-based model results had to be adjusted. This is because the model distributes shop trips to large zones far away from the mall, as illustrated in Figure 35. This is not realistic and is caused by the adaptation in the deterrence function of some large zones (see Section 3.3.2.3.2). Indeed, these distant French and German zones correspond to the zones which the deterrence functions null values were modified to 0.001. Values even smaller than 0.001 could solve this issue. Nonetheless, hardly any trip was assigned to them. Only 0.2% of the H-S trips came from those zones, while less than one S-H trip in total goes there. Thus, it is reasonable to remove them from the comparison. However, the trip-based model distribution might have been affected by the adjustment in those deterrence functions, even though most of those zones' trips are intrazonal. Nevertheless, the effects of those trips in the trip frequency distribution and average trip length of Trefcenter were minimal.

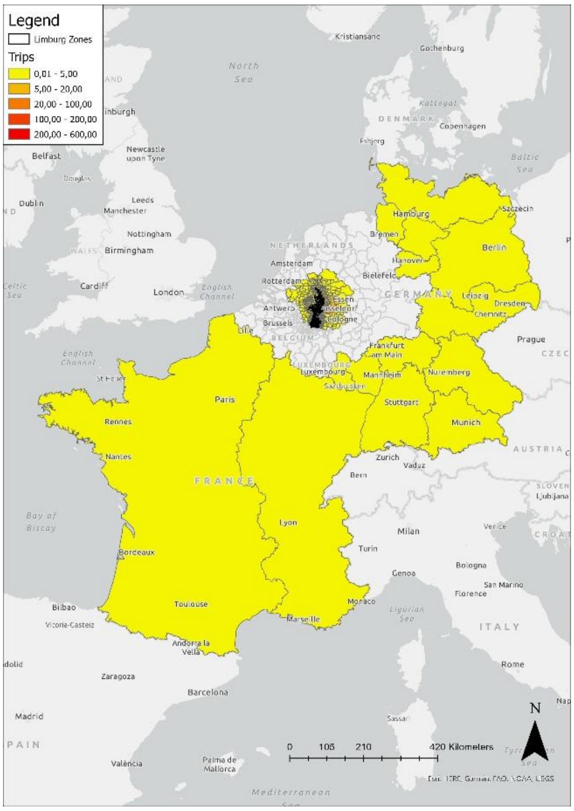

Figure 35: H-S trips to Trefcenter Venlo zone in trip-based model

a. Trip frequency distribution

The Home-Shop trip frequency distributions can be seen in Figures 36 and 37, while Figures 38 and 39 show the distribution of the post-trips.

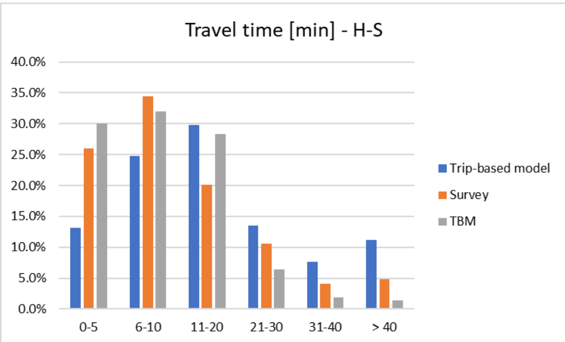

Figure 36: Travel time frequency distribution of pre-trips

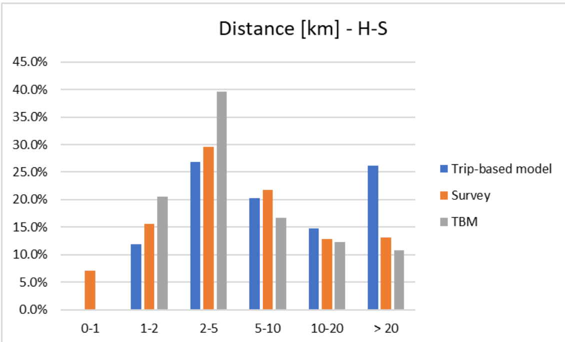

Figure 37: Distance frequency distribution of pre-trips

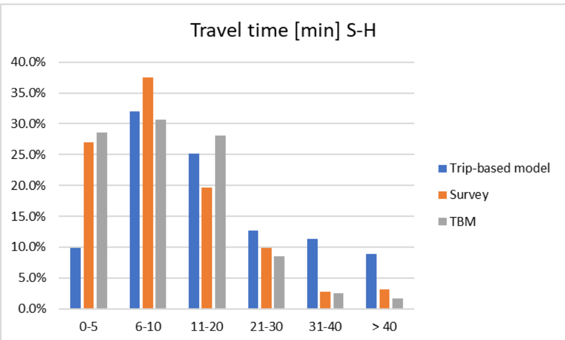

Figure 38: Travel time frequency distribution of post-trips

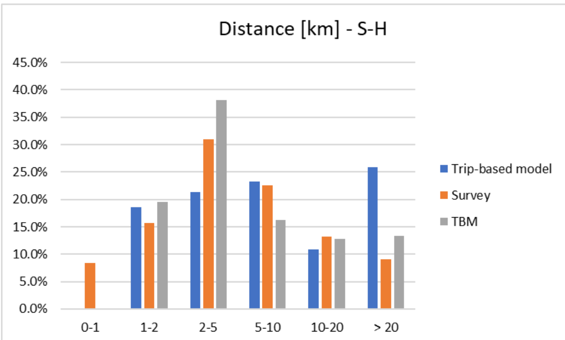

Figure 39: Distance frequency distribution of post-trips

The trip-based model distribution is significantly higher in the last class, which means that longer trips occur more often in that model. Also, the model underestimates shorter trips, at least in travel time. Note that trips within 1 kilometre are not displayed for the models as they are intrazonal. The trips displayed for the survey correspond to visitors travelling to neighbouring zones, since the mall is located on the border of Trefcenter zone.

Furthermore, the comparison between the models and the survey based on the average RSEs of the six classes is shown in Table 33.

Table 33: Average RSE in percentage points (p.p.) of trip frequency distributions

	TBM	**Trip-based**
H-S travel time [min]	4.10	7.51
H-S distance [km]	4.99	4.98
S-H travel time [min]	3.33	7.55
S-H distance [km]	5.07	6.79

The TBM performs better than the trip-based model in the post-trips. Both the travel time and distance distributions deviate less from the survey results. However, the differences are smaller in the pre-trips, and the trip-based model replicates slightly better the distance of the Home-Shop trips. Despite, it can be concluded that the TBM is better to model the trip frequency distributions of the visitors of the mall.

An additional analysis of the trip frequency is made by splitting the classes into three groups. They are the short (2 first classes), mid-length (2 intermediate classes), and long trips (2 last classes). The average RSE of these groups are shown in Table 34. The trip-based model performs better for mid-length groups, except for travel time of pre-trips which is similar to the TBM. In addition, the results reinforce that the trip-based model is limited in the extremes, as it does not properly replicate short and long trips.

Table 34: Average RSE in percentage points (p.p.) of trip frequency distribution groups

	Short trips		**Mid-length trips**		**Long trips**	
	TBM	**Trip-based**	**TBM**	**Trip-based**	**TBM**	**Trip-based**
H-S travel time [min]	3.3	11.3	6.2	6.3	2.8	5.0
H-S distance [km]	6.0	5.4	7.6	2.0	1.4	7.5
S-H travel time [min]	4.2	11.3	4.9	4.2	0.9	7.1
S-H distance [km]	6.1	5.6	6.7	5.2	2.3	9.6

b. Average trip length

The average travel times and average distances of the trips can be seen in Table 35. It is important to mention that although the total skims – which were used to distribute the trips among the zones in the models – corresponds to travel time, they were not used in the average trip length calculation. This is because they include multiple components which were probably not considered by the respondents of the survey when stating their travel times. Thus, it is fairer to compare the actual trip travel time of the models with the survey. Otherwise, higher averages would be obtained in the models.

Table 35: Average trip lengths

	TBM	Trip-based	Survey
H-S travel time [min]	10.16	18.30	12.72
H-S distance [km]	8.60	12.69	8.80
S-H travel time [min]	10.87	18.01	11.46
S-H distance [km]	9.34	12.17	7.77

Interestingly, the trips are longer in the trip-based model. This was not expected based on the survey results, which showed longer trips of visitors in a tour (see Section 4.1.1.3). Moreover, the TBM average values are closer to the observed on the survey. Therefore, the TBM is better to estimate the trip length of the visitors of Trefcenter Venlo. It is important to reinforce that the average trip lengths were calculated using the middle values of the classes, also for the models. Thus, in case the exact skim values were used, the trip-based model would probably perform even worse because of the higher frequency in the last class. Additionally, when comparing the trip-based model with the fourth-and-back trips of the survey, the average trip lengths deviate even more (see Table 16).

One possible explanation of the higher trip length of the trip-based model lies in the car iteration to consider effects of congestion (see Section 2 – Appendix B). The TBM assigns less car trips to the network than the trip-based model in the first iteration (see Table 36). Thus, the update of the skims results in higher generalised costs between the zones for the trip-based model. This means that trips going to the same destinations take longer in the trip-based model. Nonetheless, the reasons for the higher trip length can be confirmed by analysing the home locations of the visitors of the mall in the following criterion.

Table 36: Non-intrazonal car trips in the first and second iterations

	Iteration 1		Iteration 2	
	TBM	**Trip-based**	**TBM**	**Trip-based**
Home-Shop	498,436	584,777	509,282	556,594
Shop-Home	586,075	774,085	593,463	727,634
Total	**7,418,744**	**7,894,324**	**7,534,592**	**7,487,037**

3. Home location

This criterion compares the home location of the visitors of Trefcenter Venlo and how the models replicate that. The distribution of the Home-Shop trips is analysed first. Subsequently, the distribution of the post-trips (i.e., Shop-Home) is presented.

a. Pre-trips

Figures 40 and 41 show the zones where the visitors of the mall come from, according to the models.

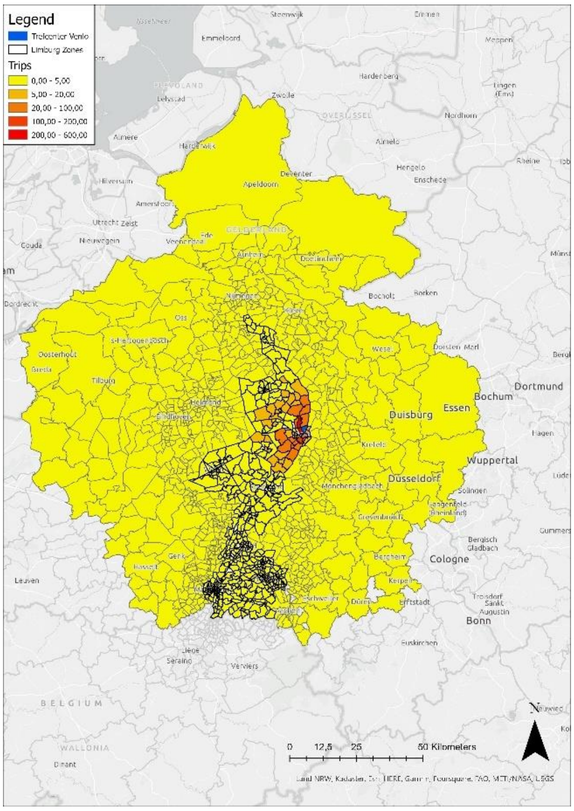

Figure 40: H-S trips to Trefcenter of TBM

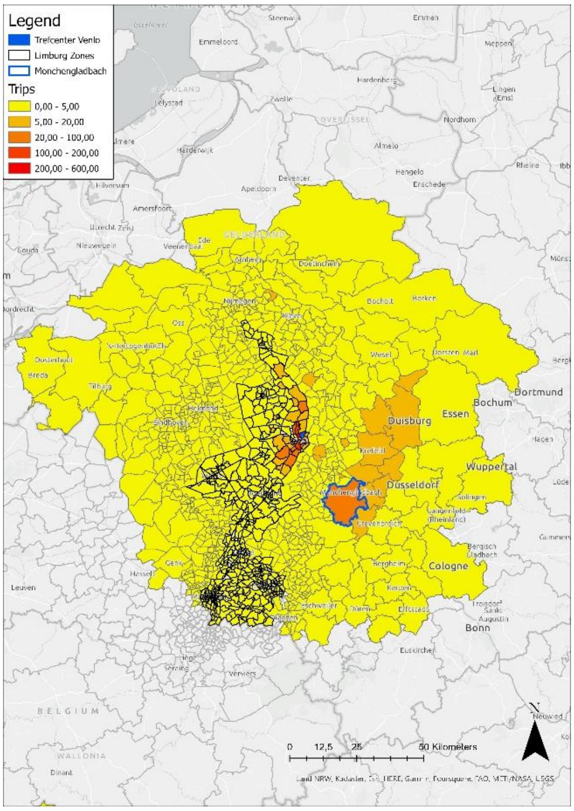

Figure 41: H-S trips to Trefcenter of trip-based model

The TBM shows that most of the visitors come from zones nearby Venlo. It distributes trips further than the trip-based model inside Limburg. In addition, there is a clear distinction in the border with Germany, as the model indicates a higher attraction of Dutch visitors. On the other hand, many trips come from Germany in the trip-based model, especially from middle-sized zones in that country. This could explain the longer travel times and distances of the trip-based model. Nonetheless, the countries' border barrier could be justified by two reasons. First, the non-intrazonal trips were compared for both models. For this purpose, a zone in Germany (i.e., Monchengladbach) was investigated (see Figure 41). Most of the Home-Shop trips produced by Monchengladbach are intrazonal. However, while in the TBM less than 2% (677) of the H-S trips are non-intrazonal, this value is about 8% (3,307) in the trip-based model. This could be an indication why many people from Monchengladbach go shop at Trefcenter. However, this hypothesis is rejected by the Work purposes analysed in Section 4.2.3.2. This is because more trips of purpose H-W are attracted to Monchengladbach in the TBM (22,462 vs 10,529). This means that more people from outside Monchengladbach go to work in the city in the TBM. However, they do not come from Trefcenter Venlo, whereas in the trip-based model they do.

The second reason concerns the intrinsic distribution difference between the models. Crossing the border between the Netherlands and Germany implies higher costs due to the Cross-border skim (see Table 46 – Appendix C). This skim is incorporated once in the trip-based model for trips that cross the border. However, in the TBM the skim is incorporated twice since the tours must return to the origin country. For instance, consider someone who lives in Monchengladbach making a HSH tour to Trefcenter. Not only the H-S trips would incorporate the Cross-border skim according to the Shop factor (see Tables 47-49 – Appendix C) – like in the trip-based model, but also the S-H trips according to the Home factor, which is even higher. Thus, tours are likely to entirely happen within the same country.

Furthermore, interestingly, visitors even from Stuttgart and Brussels responded to the survey, as can be seen in Figure 42. However, it is unlikely that they travelled so long for shopping. They might have misunderstood the question of the survey. Thus, they are ignored in this comparison.

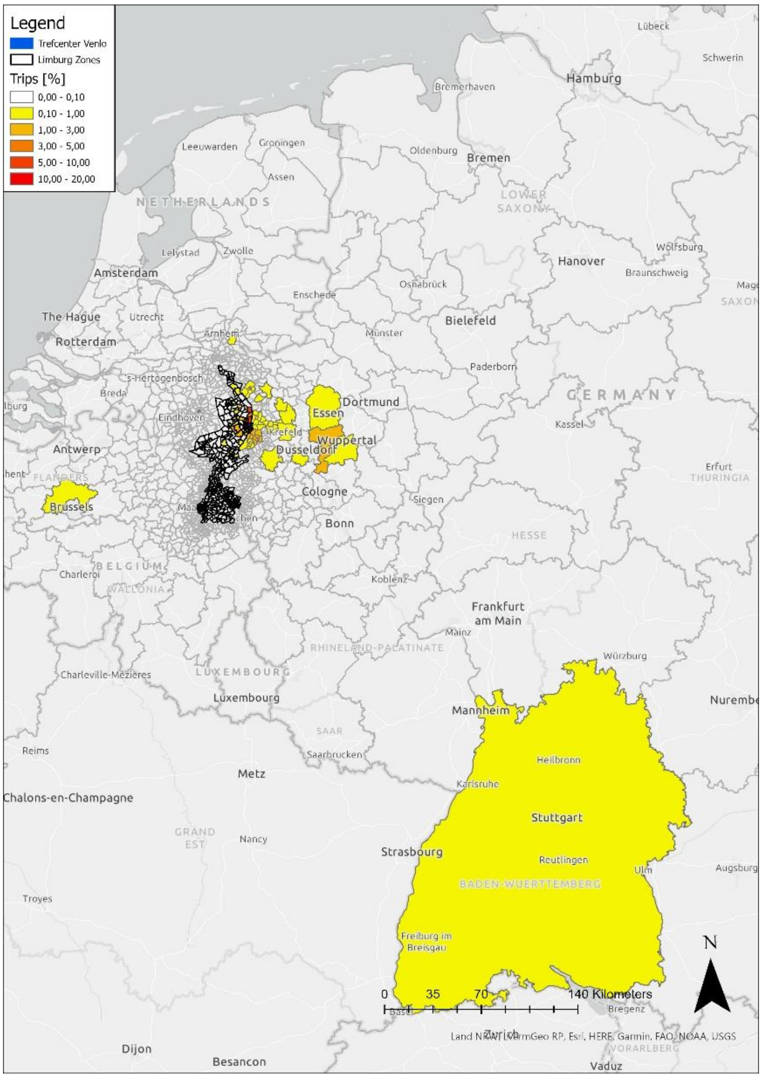

Figure 42: Home location of respondents of the survey

Finally, the distribution of H-S trips in percentages are compared to the survey results (see Figures 43-45). The survey shows that the actual visitors of the mall come mostly from neighbouring Dutch zones of Trefcenter Venlo, agreeing with the models. However, the border with Germany is not a hindrance for them, as many visitors do come from German zones. Thus, the trip-based model better replicates the distribution of the visitors' home location in the pre-trip.

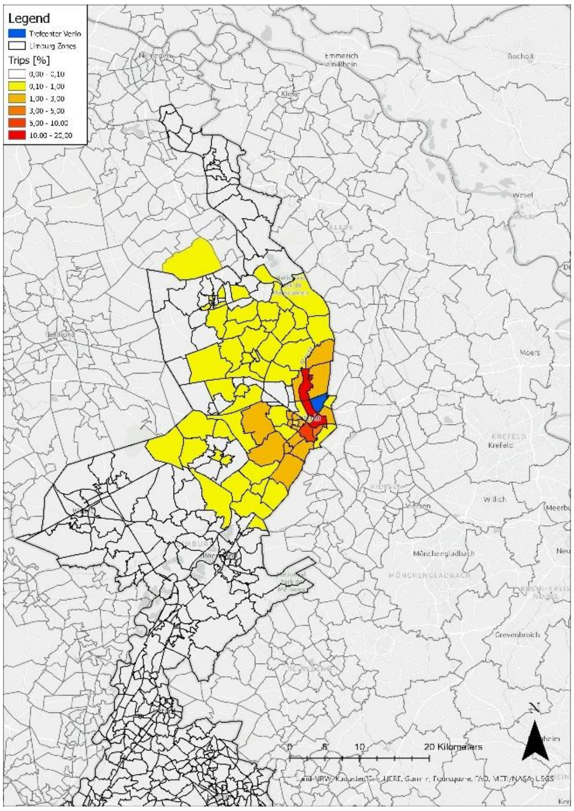
Figure 43: H-S trips of TBM

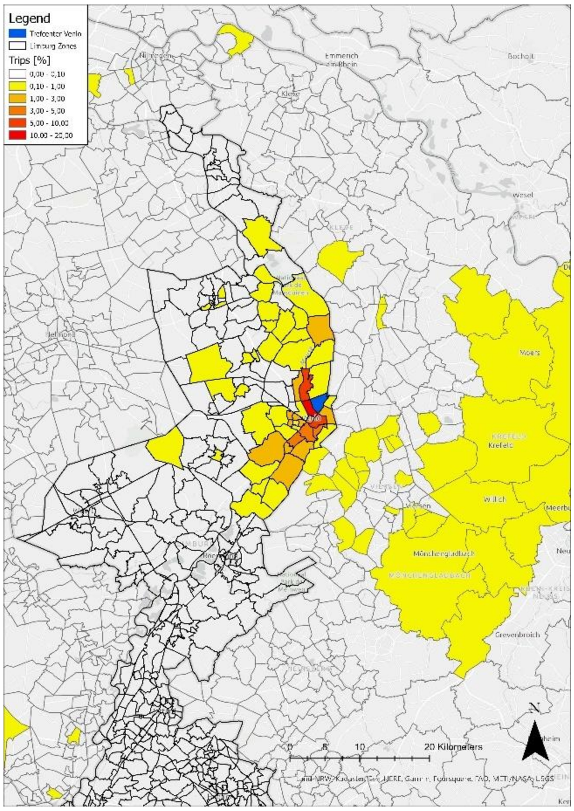
Figure 44: H-S trips of trip-based model

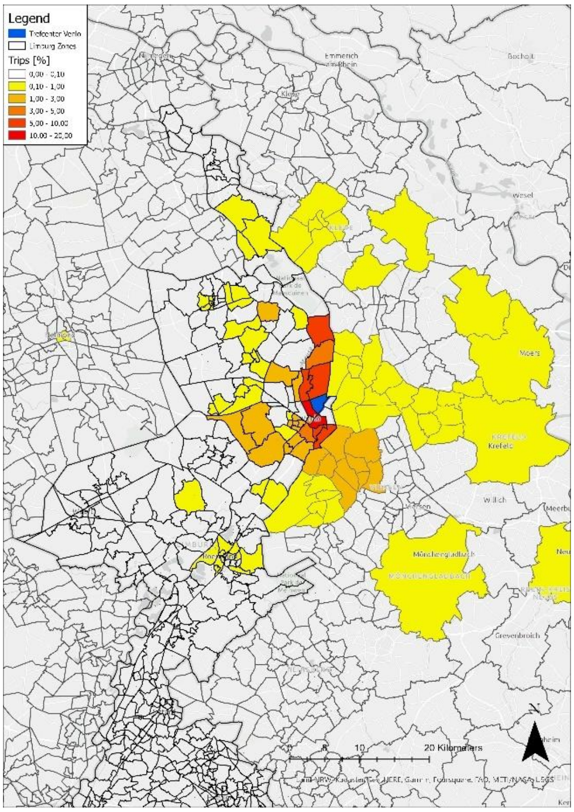
Figure 45: H-S trips of survey

b. Post-trips

Figures 46 and 47 show where the Shop-Home trips from the mall are assigned to by the models. The distribution of visitors in the post-trips of the TBM is similar to the pre-trips. However, differences can be observed when comparing the trip-based model maps. Visitors going back home reach farther zones in the Netherlands, while less regions in the west of Germany receive trips. This shows the inconsistency of the trip-based model when not linking the trips. Moreover, the German border restricts trips in the TBM again. On the other hand, even more trips are assigned to German zones in the trip-based model, especially near Monchengladbach.

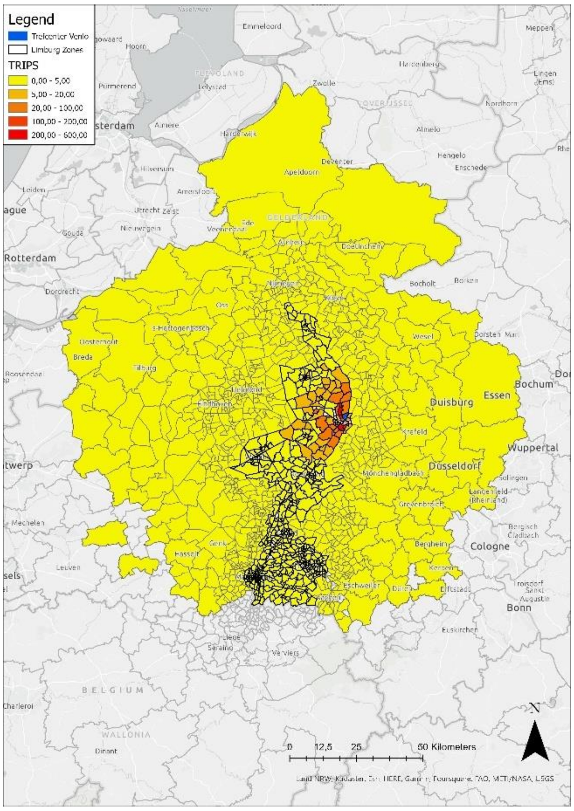

Figure 46: S-H trips from Trefcenter of TBM

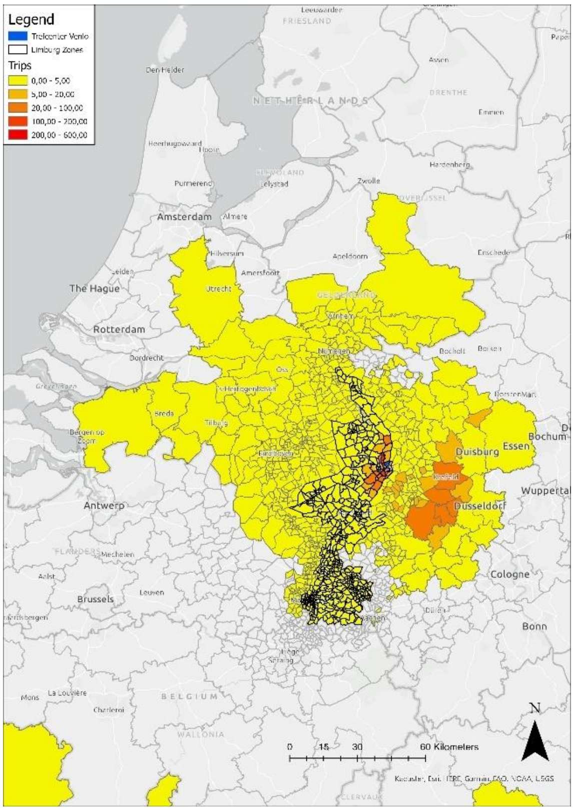

Figure 47: S-H trips from Trefcenter of trip-based model

Further, comparing the trip percentages of the models with the survey (see Figures 48-50), similar conclusions to the pre-trips can be drawn. Therefore, the trip-based model better replicates also the post-trips of visitors of Trefcenter Venlo. Again, the TBM seems to overestimate the border resistance, i.e., the Cross-border skim is high.

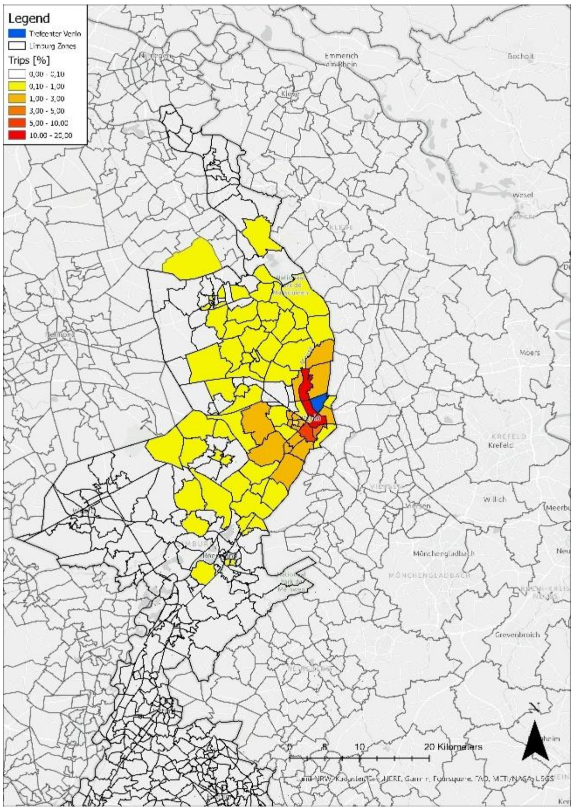

Figure 48: S-H trips of TBM

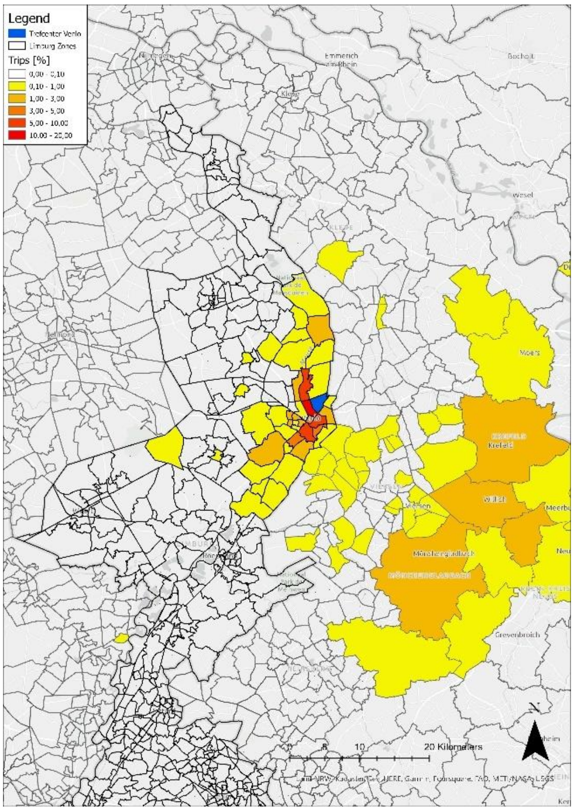

Figure 49: S-H trips of trip-based model

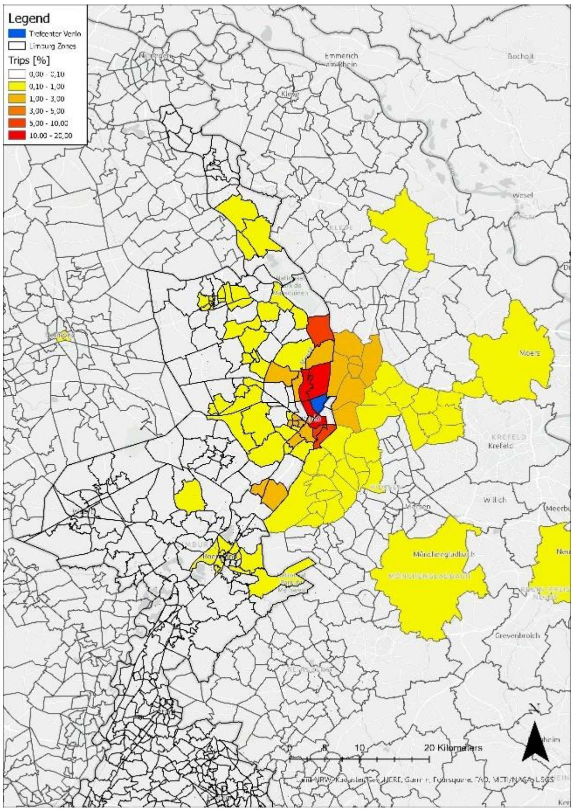

Figure 50: S-H trips of survey

4.3.2 Comparison with traffic counts

4. Trip assignment

The trip assignment comparison is presented in this section. The results of the TBM are shown in Table 37 and the trip-based model in Table 38.

Table 37: T-values of TBM

T-value	Car		Bicycle		PT	
T < 3.5	302	18.9%	17	11.1%	65	23.3%
3.5 < T < 4.5	184	11.5%	11	7.2%	36	12.9%
T > 4.5	1115	69.6%	125	81.7%	178	63.8%

Table 38: T-values of trip-based model

T-value	Car		Bicycle		PT	
T < 3.5	98	6.1%	8	5.2%	48	17.2%
3.5 < T < 4.5	64	4.0%	12	7.8%	31	11.1%
T > 4.5	1439	89.9%	133	86.9%	200	71.7%

The results show that the synthetic TBM replicates the trips assigned to the network better than the trip-based model no matter the transport mode. Yet, they are poorly estimated as more than 60% are not acceptable for any mode.

5 Discussion

The significant number of visitors in a tour (i.e., pre-activity different than post-activity) presented by the survey (about 30%) set higher expectations regarding potential advantages of the TBM over the trip-based model in this research. This indeed was partially confirmed as the TBM better replicates the modal split and trip length of the Shop trips of Trefcenter Venlo. However, it is important to discuss the potential causes and hindrances of the obtained results.

5.1 Modal split

One of the intrinsic differences between the models concerns modal spilt. While the TBM constrains the change of modes within a tour, the trip-based model can be inconsistent on the modal shares of departures and arrivals since these trips are not interlinked. This inconsistency was shown in this research. Moreover, the differences on the modal share per purpose were also explained, which helped to identify one important deficiency of the trip-based model developed in this research. That is, it does not properly represent people under 18 years old which cannot drive. Thus, higher car share was observed for some purposes, especially the Education ones. This might have been partially balanced out by the higher generalised costs in the trip-based model for car. In summary, the distribution functions used in the trip-based model misrepresent people under 18 years old by enabling them to travel by car. This results in more cars assigned to the network in the first iteration, leading to higher skims in the trip-based model. Finally, these skims reduce the car share in the second iteration.

Therefore, the modal split of the trip-based model developed in this research is flawed. This was reflected in the comparison with the survey, as the TBM better replicates the modal shares. It is important to emphasise that the distribution functions of the trip-based model can be improved to properly average out different age groups. However, this would still be a median, thus inaccurate behaviour is expected. Nonetheless, the fact that the TBM by nature distinguishes groups of people according to different characteristics such as age is an advantage of the model. Thus, it better reproduces trips of students, for example. Yet, although better than the trip-based model, the modal split of the TBM considerably differs from the survey. The model underestimate car and overestimate bike and PT shares. This lies in the fact that shopping characteristics are not discerned in the Shop deterrence functions, which aggregates, for instance, shops of major cities like Amsterdam, as well as shopping malls in historical small city centres.

Finally, the aforementioned drawbacks do not allow to deduce if the advantage of the TBM in the estimation of modal shares obtained in this research relies exclusively on the intrinsic characteristic of the tour approach. This benefit is likely a result of the specific case investigated in this research and could differ for other analysis.

5.2 Trip length

The trip length of the pre- and post-trips of the visitors of the mall were compared based on the trip frequency distribution and the average trip length. The TBM better replicates the travel time and distance of the visitors. However, whether this is purely due to the different approaches of the models is inconclusive. This is because of two reasons. First, the trip-based model is hindered by the higher car skims, which is not a characteristic of the model itself, but a limitation of how it was developed in this research – i.e., higher car skims due to misrepresentation of people under 18 years old in the distribution functions. This limitation hinders both short and long trips of the model. Short trip is a well-known issue of traffic modellers. They are not only often forgotten by respondents of travel surveys such as OViN, but also poorly addressed in models due to the aggregation of data in zones. Long trips are also affected in the trip-based model by the higher car skims since traveling to the same destination would be faster/shorter in the TBM. Interestingly, mid-length trips were better modelled by the trip-based model. Second, although the trips distributed to Germany seems to play a major role in the poor estimation of trip length by the trip-based model, the TBM's trip-length would likely deviate in case the Cross-border skim of activity Home was corrected. This is because the correction of that skim is expected to generate tours to Germany more frequently.

5.3 Home location

The analysis of how the models replicate the home location of the visitors of the mall highlights one of the causes of the higher trip lengths obtained with the trip-based model. Although closer distributed in Limburg, many trips to middle-sized German zones significantly increase the travel times and distances of the visitors of the mall in that model. Despite that, the comparison with the survey shows that a considerable number of visitors of the mall indeed comes from Germany. For this reason, it is concluded that the trip-based model better replicates the home location of the visitors of the mall, for both H-S and S-H purposes. However, it is important to highlight some points. First, the pattern observed in middle-sized German zones in the trip-based model is not accurately reflected in the survey. The visitors come mostly from small zones near the border. Second, the conclusion could be different in case the Cross-border skim values of activity Home was corrected. Therefore, the disadvantage of the TBM stated in this section is merely a limitation of this research and not a drawback of the approach itself.

5.4 Trip assignment

The comparison with traffic counts showed that the TBM better replicates the trips assigned to the network. However, it is difficult to associate this advantage to the intrinsic characteristics of the models since many choices in the development of the trip-based model were made in benefit of the TBM – e.g., adjustment of the function to exclude intrazonal trips. Thus, it is likely that the deficiencies of the development of this research are responsible for the poor T-values of the trip assignment of both models.

5.5 Overall conclusion

This research has identified some potential advantages of the TBM over the trip-based model in the analysis of shopping trips in Limburg. The modal split, trip length, and trip assignment were better replicated by the TBM. However, it was not possible to conclude if those advantages are solely due to the differences in intrinsic characteristics of the models. The identification of these intrinsic differences was not easy due to flaws on the development of the models. Mainly, the calculation of intrazonal trips based on the areas of the zones, the misrepresentation of people under 18 years old in the distribution functions, and the Cross-border skim hindered assertive conclusions regarding the benefits of the tour-based approach over the trip-based model. Therefore, the observed advantages most likely concern the specific case investigated in this research. It is possible that the analysis of other shopping facility (e.g., a supermarket) or other trip purposes could lead to different outcomes.

It should be mentioned that the enhancement of the models developed in this research is expected to benefit even more the TBM's modal split criterion. This is because properly addressing people under 18 years old in the trip-based model, as well as enhancing the Cross-border skim is expected to reduce the car share in the trip-based model and increase it in the

TBM. Unfortunately, this could not be investigated, but if confirmed, it suggests that the TBM is more appropriate for emerging policies which aims to incentivise sustainable mobility. Thus, forecasting traffic demand with the TBM would lead to more accurate modal shares and hence more effective interventions and efficient decision making. Nevertheless, this research provides relevant insights to the transport field, especially considering that few comparisons between tour- and trip-based models have been performed.

5.6 Research limitations

This section gives an overview of the most important limitations of this research.

5.6.1 Trip-based model limitations

The main limitation of this research is the exclusion of intrazonal trips from the trip-based model. This was necessary because of the extremely high number of non-intrazonal trips generated by large zones, which would certainly hinder the traffic forecast. This exclusion affected the trip distribution in different ways. Firstly, it influenced the departures and arrivals of the different analysed groups of zones. The middle-sized and large zones of the trip-based model generate considerably less trips than the TBM. Nonetheless, Trefcenter Venlo zone was not hindered by this limitation, as its generation is similar for both models. Secondly, the exclusion of intrazonal trips created a constraint in the trip-based model. That is, the percentages of non-intrazonal trips are the same for departures and arrivals. However, in reality, these percentages are expected to largely differ for some purposes, as exemplified for S-H trips in a commercial hub like Utrecht. Therefore, the generation of some purposes is limited in the trip-based model, especially for middle-sized and large zones. Again, small zones, including Trefcenter Venlo, were less affected and the comparison with the survey was not hindered.

Another limitation of the trip-based model is that it does not interlink the trips. This is a well-known disadvantage of the model among academics and practitioners. Yet, it is important to highlight its effects as observed in this research. The modal shares of departures and arrivals are inconsistent in some small zones, especially the ones in city centres. Car is considerably less attractive for inward trips probably due to parking costs in central zones. In contrast, the TBM balances the trips generated per zone since every tour starts and finishes at the same place. That inconsistency was not observed in the modal share of Trefcenter zone, which is similar for both the outward and inward trips. However, the home location of visitors of the mall replicated by the model is divergent. The zones where the H-S trips come from differ from the zones where the S-H trips go to, especially the farther ones.

5.6.2 Cross-border skim

Moreover, the Cross-border skim has been presented as the main hindrance of international trips in the TBM. It increases the generalised costs of trips between two countries for all activities. However, this was likely due to the high values of the factors for purpose Home (see Tables 47-49 – Appendix C). This value is higher than almost all other activities, which means that in a tour with a single activity the trip returning home would cost more than the primary activity. Lower or even null factors would probably facilitate tours to Germany in the TBM. Moreover, this is also a limitation of the trip-based approach, which uses the same factors for W-H, S-H, E-H, and B-H. Therefore, similar corrections could attenuate the differences between H-S and S-H trips of the mall in the model.

5.6.3 Distribution functions

Furthermore, the analysis of the modal split per purpose highlighted an additional issue of the trip-based model. Unrealistic modal shares of Education purposes were obtained. This is because it does not encompass people's characteristics, such as age. In the TBM students under 18 years old do not travel by car even though they have it available in the household. However, the trip-based model ignores it and most of the study trips are made by car. In addition, this limitation was clearly observed for Education purposes, but it affects all other activities as well, especially Other, which kids and teenagers are more likely to perform.

Finally, another limitation of the models is that their Shop deterrence functions do not distinguish shopping characteristics. The behaviour of visitors of a shopping mall like Trefcenter Venlo is different from the visitors of a supermarket in Utrecht, for instance. However, a single function (per mode) is used for Shop trips. An improvement could be made by differentiating those trips based on the urban degree, for example.

6 Conclusion

This research analysed the travel behaviour of the visitors of Trefcenter Venlo shopping mall in Limburg. Traffic counts as well as the actual behaviour of visitors obtained with a survey were compared to the tour- and the trip-based models aiming to demonstrate the benefits of the TBM in practice. This is discussed in this section, where the research questions are answered. In addition, reflections on the research goal as well as recommendations for future research are also presented.

6.1 Answering research questions

The three sub-questions and the main research question formulated for this study are answered in the following sub-sections.

6.1.1 Travel behaviour of visitors of Trefcenter Venlo

Sub-question 1 was stated as:

What is the actual travel behaviour of visitors of the shopping mall?

The travel behaviour of the visitors of Trefcenter Venlo was obtained by means of a survey, which was conducted with the visitors of the mall. Almost 30% of the visitors who responded it were in a tour. This is a representative amount which is, in theory, misrepresented in the trip-based model. This set higher expectations of a more accurate prediction of the travel behaviour by the TBM. Moreover, this behaviour differs per activity as follows:

- Home: home-based trips of the mall are longer. This was expected since large shopping malls attract people from distant places.

- Other: Other trips are relatively long. People might be willing to travel longer because those trips are mostly for leisure activities. As a consequence, most of them are made by car.

- Shop: among the analysed activities (i.e., Home, Shop, Work, and Other), trips to another shopping facility are the shortest. They are probably coming from or going to neighbouring zones, where many supermarkets can be found.

- Work: people clearly prefer to shop after work. In addition, work trips are relatively short. Consequently, lower car share and higher share of active modes were observed for this purpose.

Furthermore, the analysis of the responses distinguishing whether visitors were in a tour or not is even more relevant for this research. Visitors who were in a tour travelled longer, no matter their pre- or post-activity. This was expected since people often shop at the nearest facility when not in a tour (i.e., fourth-and-back trips). Moreover, regarding modal split, car is more attractive for people in tours. This was expected due to the flexibility of this modal. In addition, people in fourth-and-back trips use bike more often, which is logical since those trips are shorter. Finally, it is interesting to compare pre- and post-trips. Regardless the activity, trips going to the mall are longer than post-trips. This was observed even for fourth-and-back trips, which is likely due to different routes on the way back.

6.1.2 Ensuring a fair comparison

Sub-question 2 was stated as:

How does the development of the models ensure a fair comparison?

To answer this question, it is important to highlight not only the main differences between the tour- and the trip-based models, but also what was made to avoid them influencing the comparison aimed in this research. The differences are listed below.

- The distinction between the purposes of the two models prevented similar outcomes in the Trip Generation step. Despite the adjustments made to balance the total trips, large differences remained for some purposes, such as Home-Education, Home-Business, and Business-Home. However, these differences did not affect the comparison with the survey since the generation of Shop trips at Trefcenter was similar for both models.

- Large zones are not properly modelled in the trip-based model. These zones' deterrence functions needed to be adapted to enable the model to work, which might have affected the Distribution step, as unrealistic trips were observed, e.g., Shop trips from France to Limburg. However, the effects on Trefcenter Venlo were not significant, as less than 2% of the trips were assigned to the large zones in the trip-based model. Thus, the modification of the deterrence functions did not affect the comparison aimed in this research.

- The intrazonal trips excluded from the trip-based model might have affected the outcomes of many zones. However, it has not hindered the comparison since the Shop trips of the mall were analogous for both models.

Finally, the trip-based model was developed aiming to eliminate as much as possible the potential issues that could hinder the comparison with the TBM. However, many choices during the development of the trip-based model were made in benefit of the TBM. This has hampered the conclusions regarding the effects of the intrinsic differences between the models in the results of the comparison. Therefore, it is believed that the aforementioned adaptations were, overall, not sufficient to perform a fair comparison.

6.1.3 Advantages and disadvantages of TBM

Sub-question 3 was stated as:

What are the advantages and disadvantages of the tour-based model when replicating the shop trips at the mall?

The third research question was answered by comparing the models' results with the survey and traffic counts according to the four defined criteria, which are 1) modal split, 2) trip length, 3) home location of visitors, and 4) trip assignment.

Firstly, the modal share criterion indicates a potential advantage of the TBM, as it better replicated the modal split of the visitors of the mall. Although the development of the models has deficiencies, solving them is not expected to benefit the modal split of the trip-based model in relation to the survey. On the contrary, it might improve the accuracy of the TBM's modal split. However, this expectation could not be proved, and the modal split benefit of the TBM observed in this research is not necessarily due to the intrinsic differences between the models. Nonetheless, it is important to reinforce the need for distinction of shopping characteristics in traffic models. This is because the behaviour of visitors largely differs depending on those characteristics, and the comparison of modal split made it clear since both models considerably deviate from the observations on the survey.

Secondly, the TBM better estimates the trip length of the visitors of Trefcenter. Both the travel time and the distance frequency distributions are closer to the survey. However, the model poorly estimates trips within 2 and 10 kilometres, as well as 11 and 30 minutes. Additionally, the TBM's average trip length is closer to the observed in the survey. Despite all that, it was not possible to conclude if the superior trip length results of the TBM is due to its intrinsic characteristics. Rather, it seems to rely mostly on the limitations of the development of the models in this research.

Thirdly, the TBM trips are more dispersed in Limburg as the model concentrates trips inside the Netherlands. In addition, it hampers people traveling to other countries such as Germany. This border barrier is not observed on the survey, as many visitors come from neighbouring German zones. Therefore, the TBM does not replicate adequately the home location of the visitors of the mall, neither for H-S trips nor for S-H. Nevertheless, a potential improvement in the Cross-border skim was indicated in this research, which is expected to facilitate cross-boundary trips in the TBM.

Lastly, although the TBM better replicates the trips assigned to the network, the poor scores of the model hinder this criterion. This is probably because of the flaws in the development of the models that also limited the other criteria. Thus, this advantage of the TBM is not necessarily a result of its intrinsic characteristic.

6.1.4 Main research question

Finally, the main research question was stated as:

> *What are the benefits of the tour-based traffic demand model over the classic trip-based model for the analysis of the trip characteristics of a shopping mall in the province of Limburg?*

The benefits of the TBM over the trip-based model showed in this research are, unfortunately, not strictly due to the intrinsic characteristics of the models. The limitations in the development of the models did not allow to conclude whether the tour approach is the reason for the better replication of the modal split, trip length, and trip assignment by the TBM. Nevertheless, the modal split results are interesting since improving the hindrances for the comparison of this criterion is expected to favour the TBM. If that is confirmed, the TBM would be more appropriate for dealing with management-oriented policies which aims to incentivise sustainable modes of transport.

6.2 Reflection on research goal

The goal stated in this research is to evaluate and demonstrate the advantages of the tour-based model in practice. Unfortunately, although the TBM's overall performance in relation to the real observations was better, it was not possible to deduce whether this is an advantage of the tour approach itself. Nonetheless, this research has indicated relevant improvements that could be made in the development of the TBM. All in all, this research provides insights into potential advantages of the TBM which help practitioners in the transition to advanced modelling. This transition is not an easy task, and the first steps need to be taken. RHDHV has recently developed the tour-based model for Limburg and will continue to implement it to enhance the traffic system in the Netherlands.

6.3 Recommendation for future research

Based on the outcomes and the limitations of this research, it is important to highlight points of improvement and recommend additional subjects to future research.

First of all, as previously discussed, the main limitation of this research concerns the exclusion of intrazonal trips from the trip-based model. Unfortunately, it was necessary due to the difficulty of the trip-based model on estimating trips of large zones. Although it has not hindered the comparison performed in this research, the understanding of the relation between zone area and intrazonal trips is essential. Thus, the improvement of the function to remove intrazonal trips from the trip-based model is recommended for future research.

Second, although the survey provided a good sample of the visitors of the mall, a single day of analysis might not represent accurately their behaviour. More data would not only enable the evaluation of different activities, but also contribute to a better representation of reality. Unfortunately, conducting the survey in different days was not possible in this research due to limited resources. Nevertheless, it should be emphasised that the acquired sample provided relevant insights into the visitors' behaviour. Moreover, storing the exact time of response to the survey would enable an additional analysis to this research. This concerns the behaviour of the visitors in different day parts. Unfortunately, the company hired to conduct the survey could not provide it.

Third, the adjustments made on the deterrence functions of some large zones in the trip-based model resulted in unrealistic trips between them and Limburg. Although they were not significant in Trefcenter zone, they might have affected the trips throughout the study area. Therefore, the 0.001 value could be reduced even more to complicate the distribution of trips to zones distant from large zones.

Fourth, the distribution functions in the TBM mainly distinguish whether people have car available or not. In addition, they also differ for people under 18 years old for car. Therefore, deriving additional functions taking into consideration person characteristics such as age groups and income level is recommended for future research. This may enhance the accuracy in the destination and mode choice of travellers, representing reality better.

Fifth, unfortunately, an assessment of the car availability of the models could not be made. This feature is intrinsic to the TBM in the personas, derived from OViN, whereas the calculations in the trip-based model encompass the average car ownership per household in the zones. In addition, the matrices resulted from the TBM do not distinguish car availability, which impedes the comparison with the trip-based model. Differences in car availability could affect the results of the models, especially modal split. Therefore, the investigation of car availability determined for the personas of the TBM is suggested for further research.

Sixth, part of this research deeply investigated the trips of three groups of zones. They were assumed to be representative of small, middle-sized, and large zones of the models. However, the zoning range is wide and complex, and the behaviour of the models could vary beyond those three groups. Therefore, the investigation of additional zones is suggested for further research. This could identify, for instance, some relation of how the models distribute trips throughout the zones (e.g., if TBM distributes it to more distant zones than the trip-based model). Unfortunately, the limited zone investigation in this research did not allow to conclude about it.

Lastly, the analysis of NHB trips was initially intended in this research. However, this was not possible due to purpose Other in the trip-based model, which by common practice aggregates most NHB trips. Thus, a comparison between them was not viable. Nonetheless, the TBM is expected to better estimate NHB trips. Therefore, a comparison over those trips is recommended for future research.

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Appendix A – Survey Template

1. What is your Postcode? [Only 4 numbers, no letter]
2. For what purpose do you come to the mall?
    a. Work
    b. Shop
    c. Business
    d. Other
3. What was the travel time of your trip to the mall? [NOT MANDATORY]
    a. 0-5 minutes
    b. 6-10 minutes
    c. 11-20 minutes
    d. 21-30 minutes
    e. 31-40 minutes
    f. > 40 minutes
4. What was the travel distance of that trip? [NOT MANDATORY][5]
    a. 0-1 km
    b. 1-2 km
    c. 2-5 km
    d. 5-10 km
    e. 10-20 km
    f. > 20 km
5. Which is the activity of your previous location?
    a. Home
    b. Work
    c. Shop
    d. Education
    e. Business
    f. Delivery
    g. Other
6. Which mode of transport did you use to come to the mall?
    a. Car (driver)
    b. Car (passenger)
    c. Bicycle
    d. Electric Bike
    e. Scooter/motorcycle
    f. PT
    g. Walking
    h. Other. Which? ________
7. Which is the activity of your next destination?
    a. Home
    b. Work
    c. Shop

[5] For the travel distance questions (i.e., Q4 and Q10), option A means trips from 0 to 1 km, including. The same occurs for the other alternatives. This was agreed with DUX before the conduction of the survey.

d. Education
e. Business
f. Delivery
g. Other

8. Which mode of transport will you use to go to your next destination?
    a. Car (driver)
    b. Car (passenger)
    c. Bicycle
    d. Scooter/motorcycle
    e. Electric Bike
    f. PT
    g. Walking
    h. Other. Which? ______
9. What is the travel time of the trip to your next destination take? [NOT MANDATORY]
    a. 0-5 minutes
    b. 6-10 minutes
    c. 11-20 minutes
    d. 21-30 minutes
    e. 31-40 minutes
    f. > 40 minutes
10. What is the travel distance of that trip? [NOT MANDATORY]
    a. 0-1 km
    b. 1-2 km
    c. 2-5 km
    d. 5-10 km
    e. 10-20 km
    f. > 20 km

Appendix B – Common sub-models

The sub-models that are common for both the trip- and tour-based models are explained in this section. They are the Skim and Assignment.

1. Skim

The skims can be calculated for each transport mode and day part using initial demands as input. These demands are created based on an OD matrix with values of 1.0 for all OD pairs. The skims correspond to the "resistance" (i.e., costs) between the zones. Moreover, the Skim sub-model works like the Trip Assignment (see sub-section 2 below). It assigns the initial demand to the shortest route between two zones, which enables Aimsun to calculate the "resistance" between them. The skims are generated for different cost components. The components per mode included in this research can be seen in Table 39. In addition, the description of these components can be seen in Table 46 – Appendix C. Finally, the outputs of the Skim model are OD matrices per mode and day part for each component.

Table 39: Skim components

Mode	Components
Car	Distance (km); Travel Time; Cross-border; Parking Cost; Junction Delay
Bicycle	Travel Time; Junction Delay; Cross-border;
PT	Transfer Penalty; Fare; In-Vehicle Time; Total Waiting Time; Walking Time; Cross-border; Distance (km);

The travel time of car takes into account congestion and intersection delays, while travel time of bike considers only intersection delays. Moreover, the Distance (km) skim of PT was externally calculated with GTFS. GTFS is a worldwide standardized format for PT data introduced by Google, which includes the schedules and the locations of transit lines and stops (Esri, n.d.). Thus, it is more accurate than Aimsun's network calculation.

In addition, the Fare component is calculated for PT according to the distance of the trip. Three different equations are used as shown in Table 40. The remaining components are calculated by the Aimsun assignment algorithm.

Table 40: Equations for calculation of Fare skim depending on distance

Distance [km]	Fare
$\boldsymbol{d < 100}$	$1.08 + 0.18 * d$
$\boldsymbol{100 < d < 200}$	$10.19 + 0.09 * d$
$\boldsymbol{d \geq 200}$	27.40

Finally, the intrazonal skims are calculated based on a certain number of minimum skim values for a centroid. The average of these values is calculated and then multiplied by a factor, according to Equation 20.

$$IntraSkim_i = f^{mu} * \frac{\sum_{nrOfValues} \min(Skim_i)}{nrOfValues} \tag{20}$$

Where:

f^{ma} = intrazonal factor for mode m and urban area u.

The number of minimum skim values used in this research is 5. The factors for the different urban areas and modes of transport can be seen in Table 41. Note that the bike factors vary also within some area types. The first value corresponds to urban degrees 1 and 2, while the second value corresponds to 3, 4 and 5.

Table 41: Factors for intrazonal skim calculations

Area type	Car	Bicycle	PT
Study area (NL)	0.50	0.50/0.40	0.05
Area of influence (NL)	0.30	0.25/0.20	0.07
Outside area (NL)	0.25	0.05	0.35
Study area (BE)	0.40	0.20/0.15	0.05
Area of influence (BE)	0.25	0.10/0.05	0.07
Outside area (BE)	0.25	0.04	0.30
Study area (DE)	0.40	0.20/0.10	0.05
Area of influence (DE)	0.25	0.10/0.05	0.07
Outside area (DE)	0.25	0.04	0.30

a. Total Skim

The Total Skim process is a weighted sum of all the components generated by the Skim sub-model, resulting in what is called generalised costs. These costs are the combination of the components into the same unit, which in this research is travel time (in minutes). This includes converted monetary costs such as parking costs for cars, and public transport costs. The generalised cost of an OD pair can be calculated as follows:

$$C_{ij}^{pmt} = \sum_{c} f_c^{pm} * Skim_{cij}^{mt} \tag{21}$$

Where:

C_{ij}^{pmt} = generalised cost between origin i and destination j for purpose p, mode m and day part t;
f_c^{pm} = factor for component c, mode m and trip purpose p.

The total skims are calculated for each transport mode and day part. In addition, the component factors f_c^{pm} were taken from NRM and differ not only per mode but also purpose. This is because the components might be perceived differently depending on the motive of the trip. For example, traveling 100 kilometres for business purpose is more likely than traveling the same distance for shopping. Thus, the factor of the distance component for Business should be smaller than Shop. The total skim factors can be found in Tables 47-49 – Appendix C.

b. E-bike and PT travel time corrections

Bike and PT travel times are adjusted within the Total Skim sub-model. E-bike correction is applied to the bike travel time skim. It aims at considering the higher speeds of electric bikes. For this purpose, a factor is used to correct the travel time according to the distance between the OD pairs. This is done by simply dividing the travel time by the factor. Different factors are used depending on the maximum distance value, which are shown in Table 42. Thus, if an OD distance is below 2.5 km, a factor of 1.0 is used, while if this distance is between 2.5 and 5.0 km, a factor of 1.007 is used, and so forth. The last value (i.e., 9999) corresponds to a distance large enough to contain all OD pairs. Those factors were derived from OViN

("Onderzoek Verplaatsingen in Nederland", which means "Travel Research in the Netherlands" in English) data.

Table 42: E-bike travel time correction factors

Max. distance [km]	Factor
2.5	1.0
5.0	1.007
7.5	1.021
12.5	1.048
9999	1.096

Another correction on the travel time skim also occurs for PT. In this case, the correction aims to avoid high PT modal share to an OD-relation which is unattractive for PT. This is the case of trips where the walking part represents a relatively large portion of the whole trip compared to the actual in-vehicle part. For this purpose, a factor is multiplied by the in-vehicle travel times for certain OD-pairs. This correction is made for OD-relations which 1) the distance and the average speed are smaller than pre-specified thresholds, and 2) the fraction in-vehicle time over walking time is lower than or equal a threshold. In this research, this threshold is equal 1.0, which means that the correction is applied when the in-vehicle time is smaller than the walking time. The pre-determined thresholds and the multiplicative factor can be seen in Table 43.

Table 43: Inputs of PT travel time correction

Distance threshold [km]	10.0
Speed threshold [km/h]	15.0
Fraction threshold	1.0
Multiplicative factor	100

c. Skim24

An additional sub-model is used to aggregate the skims of the different day parts into a 24-hour period. This sub-model is the Skim24, and it is only needed in the TBM. This is because tours usually take place during a long period of the day (e.g., from morning until evening). The Skim24 employs a weighted aggregation of day part skims. In other words, the skims of each day part are multiplied by their corresponding factors and then added up for each purpose. Those factors were derived from OViN and can be found in Table 44.

Table 44: Factors for aggregation of day part skims

Activity	Morning	Rest	Evening
Home	0.0382	0.6903	0.2715
Work	0.2250	0.6359	0.1391
Business	0.1362	0.7168	0.1470
Education	0.2363	0.7023	0.0613
Shop	0.0756	0.7580	0.1664
Delivery	0.0970	0.6784	0.2246
Other	0.0363	0.7493	0.2143

2. Trip Assignment

After obtaining the distribution of the trips among the zones, the assignment of the trips to the network occurs. This is done in a first iteration only for cars. This iteration aims to take into consideration the effects of congestion on travellers' choices, which is done by re-calculating the car skims based on the assigned demand. It is worth to mention again that the freight demand is added to car demand in this step. Regarding bicycle and PT, it is assumed that the generalised costs do not change significantly with the increase in demand. Further, the assignment is performed for all modes in a final iteration.

This step uses the trip matrices to load the demands onto the network. This assignment can be (broadly) classified as either dynamic or static. Static Traffic Assignment (STA) has been widely used by transport planners for decades, and it is still preferred by many practitioners due to simplicity and lower computation resources required. However, STA fails to capture the dynamic characteristics of traffic. As flow varies with time, STA cannot address it precisely (Saw et al., 2015). On the other hand, Dynamic Traffic Assignments (DTA) can forecast traffic flow taking into consideration its time-varying characteristic. DTA is able to show the variation of congestion with time. Therefore, it is useful for traffic management and control. and can provide real-time traffic simulation to help route decisions (Saw et al., 2015).

The assignment method used in this research is STA. There are five different methods that can be applied on Aimsun to statically assign the trips to the network. Those are the 1) All or Nothing (AON), 2) Incremental, 3) Method of Successive Averages (MSA), 4) Frank & Wolfe, and 5) Stochastic assignments. First, AON calculates the paths with the lowest cost (e.g., travel time, distance, travel cost) between the OD pairs and assign the whole demand to those paths. This is the simplest method which has a major limitation of not considering the capacity of the links (Saw et al., 2015). Second, the Incremental method assigns a percentage of the demand iteratively, based on all or nothing assignments. The model updates the costs between the zones and calculates new shortest paths after each iteration (Aimsun SLU, 2021). Third, MSA uses a pre-determined number of iterations to assign the trips to the network. With a sufficient number of iterations, the method tends to converge to an equilibrium (Babazadeh & Abravan, 2009). Fourth, Frank & Wolfe is an Equilibrium Traffic Assignment method that calculates the flows according to Wardrop's principle: travel time between two zones cannot be improved by any alternative route. It takes congestion into account but has limited assumptions such as drivers choosing their route based on lowest travel time (Aimsun SLU, 2021). Finally, the Stochastic method calculates the k-best paths between the zones and splits the demand among them (Aimsun SLU, 2021). This method assumes drivers choose their routes based on perceived costs. These costs are assumed to be random variables (Saw et al., 2015).

The AON method is used to assign bicycle and PT trips in this research. The reason for bike is that the travel costs are barely affected by the number of cyclists on the road, and most of them prioritises lower travel time when choosing their route (Cui & Levinson, 2018). For PT, although some people may try to avoid busier lines, this behaviour is not a pattern among PT users, especially in the Netherlands where PT punctuality is high. Regarding car trips, the MSA method was used with 25 iterations and relative gap of 0.001.

a. Assignment24

Day part trips assigned to the network are aggregated into a 24-hour period by means of the Assignment24 sub-model. This model aggregates the demands of the different day parts by multiplying them by the day factors (see Table 45) and summing up the results. This is done for all transport modes and generates travel demand for the entire day.

Table 45: Factors for converting day parts into 24-hour period

Period	Factor
Morning	2
Evening	2
Rest	12

b. Bicycle assignment

The bike trips are assigned to the network onto 3 routes. One third of the trips are assigned to the fastest route between two zones. Another one third is assigned to the shortest route. Finally, the last third of the trips is assigned to a route which the average between distance and time is the smallest. Obviously, it is possible that more than 33% of the trips are assigned to the same route. For instance, in case this route is the fastest and the shortest between two zones.

Appendix C – Skimming

The description of the skim components is presented in Table 46, according to Aimsun SLU (2021).

Table 46: Description of skim components

Component	Description
Travel Time	Weighted mean trip times
Distance (km)	Weighted mean trip distances
Junction Delay	Weighted mean junction delay path costs
Parking Cost	Costs related to parking the car
Cross-border	Costs related to the urban system of different countries. It creates a hindrance for people traveling to a zone with a different urban system, e.g., a different country.
In-Vehicle Time	Time spent in a vehicle on a trip
Total Waiting Time	Total time spent waiting for a PT vehicle
Walking Time	Time spent walking to and from PT stops
Transfer Penalty	Perceived costs which are used in a PT trip to choose between a trip with no interchanges and one with interchanges.
Fare	The fare incurred on the trip.

The total skim factors of the different modes of transport are presented in Tables 47-49. Note that the same factors were used for both models, aligned based on the destination activity. In addition, the travel time factor is equal 1.0 for all modes.

Table 47: Total skim factors of car

TBM	Trip-based model	DistanceKM	Junction Delay	Cross-border	Parking Cost
Home	**W-H; S-H; E-H; B-H**	0.586	1.0	95.04	0
Work	**H-W**	0.586	1.0	95.04	0
Business	**H-B; B**	0.194	1.0	76.48	0
Education	**H-E**	0.602	1.0	86.92	0
Shop	**H-S**	0.602	1.0	61.10	7.1
Delivery	**-**	0.602	1.0	155.04	0
Other	**O**	0.602	1.0	73.83	7.1

Table 48: Total skim factors of bicycle

TBM	Trip-based model	Junction Delay	Cross-border
Home	**W-H; S-H; E-H; B-H**	0.5	95.04
Work	**H-W**	0.5	95.04
Business	**H-B; B**	0.5	76.48
Education	**H-E**	0.5	86.92
Shop	**H-S**	0.5	61.10
Delivery	**-**	0.5	155.04
Other	**O**	0.5	73.83

Table 49: Total skim factors of PT

TBM	Trip-based model	Total Waiting Time	Cross-border	Transfer Penalty	Fare	Walking Time
Home	**W-H; S-H; E-H; B-H**	0.5	155.04	1.0	6.0	1.0
Work	**H-W**	0.5	155.04	1.0	5.45	1.0
Business	**H-B; B**	0.5	136.48	1.0	2.31	1.0
Education	**H-E**	0.5	146.92	1.0	2.5	1.0
Shop	**H-S**	0.5	121.10	1.0	7.5	1.0
Delivery	**-**	0.5	155.04	1.0	7.5	1.0
Other	**O**	0.5	133.83	1.0	7.5	1.0

Appendix D – Socio-Economic Attributes

The socio-economic attributes of Trefcenter Venlo zone are shown in Table 50.

Table 50: Socio-economic attributes of Trefcenter Venlo zone

Attribute	Value
Detail workplaces	724
Services workplaces	765
Low services workplaces	63
Catering workplaces	101
Industry workplaces	656
Low industry workplaces	125
Agriculture workplaces	26
Education workplaces	29
Government workplaces	291
Other workplaces	815
Care workplaces	140
Car available	1390
No car available	128
Income Avg	45682
Income 0-30k	279
Income 30-50k	593
Income 50k+	646
Inhabitants	1518
Child study places	169
Age 0-17	303
Age 18-34	244
Age 35-64	688
Age 65+	283
Basic study places	389
M2 Distribution	13057
M2 Lodge	1335
M2 Supermarket	1448
M2 Other shop	119594
M2 Residential boulevard	16727
M2 Care	759
Full-time workers	473
No work	862
Part-time workers	183

The socio-economic attributes that were used in the Trip Generation step of the trip-based model can be seen in Table 51.

Table 51: Socio-economic attributes used for calculation of trip generation of the trip-based model

Purpose	Production attributes	Attraction attributes
Home-Work	Part- and full-time workers	Agriculture, industry, detail, services, government, other, care, catering, education, low industry, low services, and low care workplaces
Work-Home	Agriculture, industry, detail, services, government, other, care, catering, education, low industry, low services, and low care workplaces	Inhabitants
Home-Shop	Inhabitants	Area in squared metres of supermarket, residential boulevard, construction market, garden centre, and other shop.
Shop-Home	Detail workplaces	Inhabitants
Home-Education	Inhabitants	Basic, high-school, MBO, and HBO/WO study places
Education-Home	Basic, high-school, MBO, and HBO/WO study places	Inhabitants
Home-Business	Part- and full-time workers	Agriculture, industry, services, government, other, care, low industry, low services, and low care workplaces
Business-Home	Agriculture, industry, services, government, other, care, low industry, low services, and low care workplaces	Inhabitants
Business	Agriculture, industry, detail, services, government, other, care, catering, education, low industry, low services, and low care workplaces	Agriculture, industry, detail, services, government, other, care, catering, education, low industry, low services, and low care workplaces
Other	Inhabitants; Agriculture, industry, detail, services, government, other, care, catering, education, low industry, low services, and low care workplaces; Basic, high-school, MBO, HBO/WO, and children study places	Inhabitants; Agriculture, industry, detail, services, government, other, care, catering, education, low industry, low services, and low care workplaces; Basic, high-school, MBO, HBO/WO, and children study places

The socio-economic attributes used to calculate the attractions of the TBM are shown in Table 52. No attraction is calculated for purpose Home, therefore it was not included in the table. Also, the production side of the model is calculated according to the personas and frequency of their trips.

Table 52: Socio-economic attributes used for calculation of trip generation of the TBM

Purpose	Attraction attributes
Work	Agriculture, industry, detail, services, government, other, care, catering, education, low industry, low services, and low care workplaces
Shop	Area in squared metres of supermarket, residential boulevard, construction market, garden centre, and other shop.
Education	Basic, high-school, MBO, and HBO/WO study places
Delivery	Basic, high-school, and children study places; Area in squared metres of care
Business	Agriculture, industry, services, government, other, care, low industry, low services, and low care workplaces
Other	Inhabitants; Services, government, other, and low services workplaces; Basic, high-school, MBO, HBO/WO, and children study places; Area in squared metres of care

Appendix E – Area Types

Table 53 shows the existing area types in the Limburg model. Each area type is divided among different urban degrees. In general, five degrees of urbanization are distinguished between the zones, ranging from highly urban (1) to rural (5). However, the zones of the TBM are, in fact, even more detailed. They are distinguished per country among study areas, areas of influence, and outside area. For each of these categories, the 5 degrees of urbanization are applied (with some exceptions). For instance, the study area in Belgium (BE) is divided into highly urban (1), urban (3), and rural (5) levels, as it is for Germany (DE) study area.

Table 53: Urban degrees for different area types

Area type (Dutch)	**Area type (English)**	**Urban degree**
Studiegebied (NL)	Study area (NL)	1; 2; 3; 4; 5
Invloedsgebied (NL)	Area of influence (NL)	1; 2; 3; 4; 5
Buitengebied (NL)	Outside area (NL)	3
Studiegebied (BE)	Study area (BE)	1; 3; 5
Invloedsgebied (BE)	Area of influence (BE)	1; 3; 5
Buitengebied (BE)	Outside area (BE)	3
Studiegebied (DE)	Study area (DE)	1; 3; 5
Invloedsgebied (DE)	Area of influence (DE)	5
Buitengebied (DE)	Outside area (DE)	3

Appendix F – Survey Results

1. Trip length distributions of trips to/from Shop

Figures 51 and 52 show the travel time and distance distributions of the pre-trips coming from another shop location. Figures 53 and 54 show it for post-trips going to another shop location.

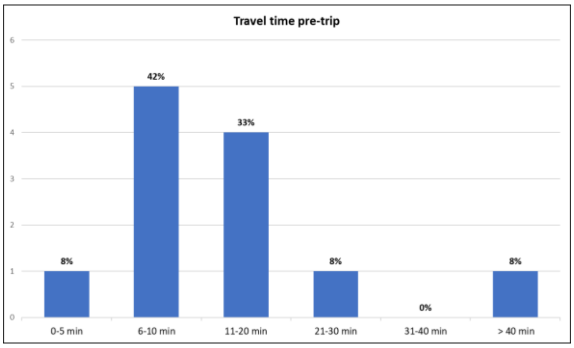

Figure 51: Travel time distribution of trips with Shop as pre-activity

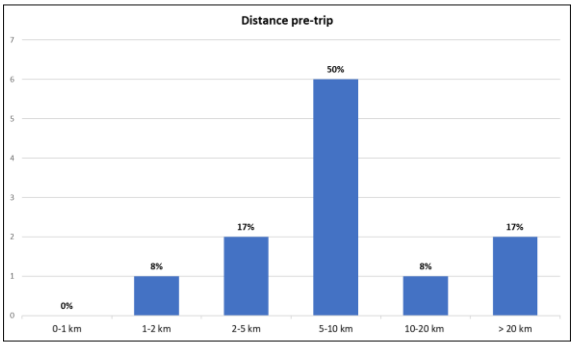

Figure 52: Distance distribution of trips with Shop as pre-activity

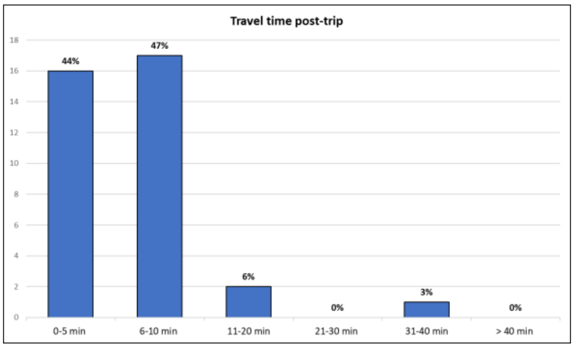

Figure 53: Travel time distribution of trips with Shop as post-activity

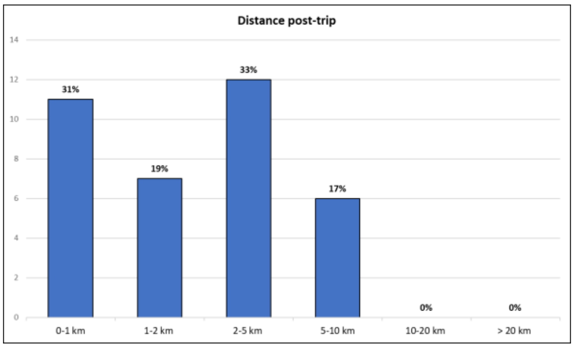

Figure 54: Distance distribution of trips with Shop as post-activity

2. Pre- and post-trips overall results

Figures 55 and 56 show the modal shares of pre- and post-trips, respectively. Figures 57 and 58 show the pre- and post-activities.

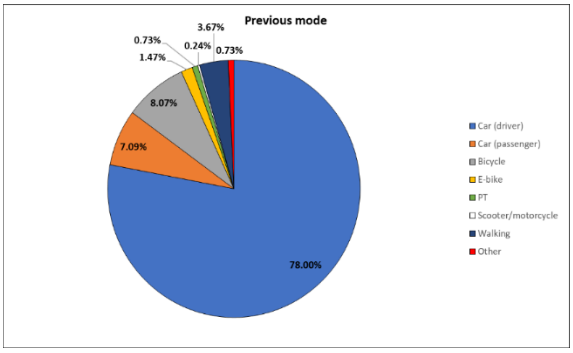

Figure 55: Modal share of pre-trip

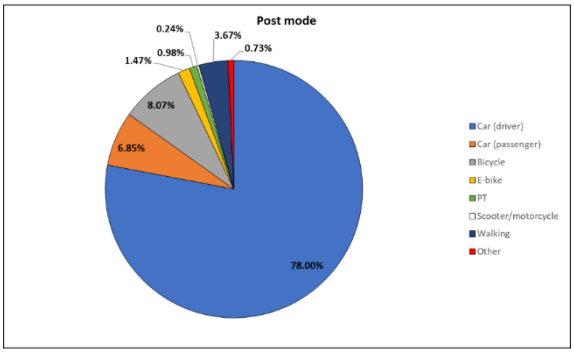

Figure 56: Modal share of post-trip

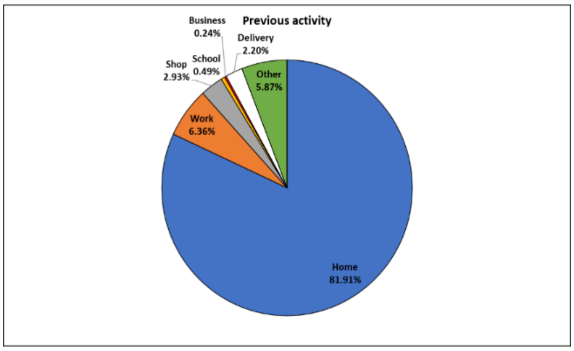

Figure 57: Pre-activities of visitors

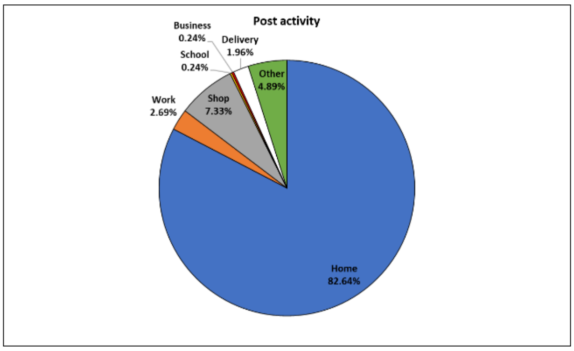

Figure 58: Post-activities of visitors

Moreover, Figures 59 and 61 show the travel time and distance distribution of the pre-trips, while Figures 60 and 62 presents it for the post-trips.

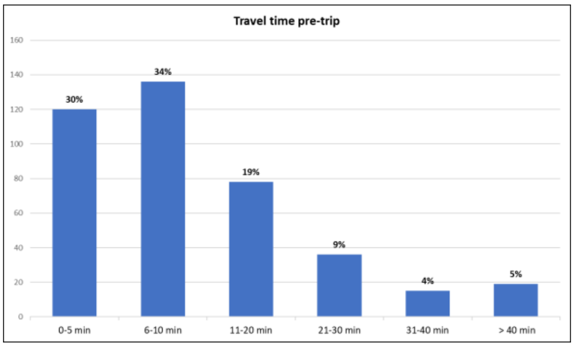

Figure 59: Travel time distribution of pre-trips

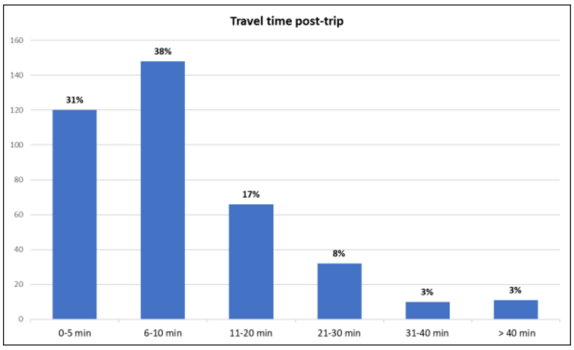

Figure 60: Travel time distribution of post-trips

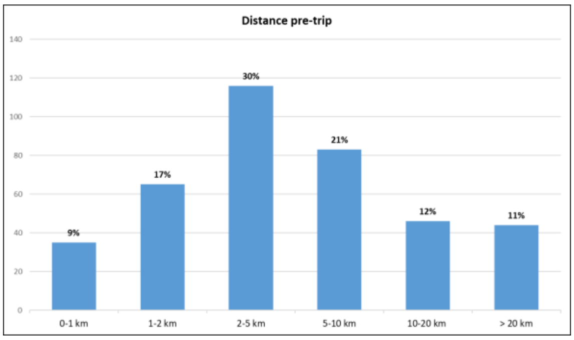

Figure 61: Distance distribution of pre-trips

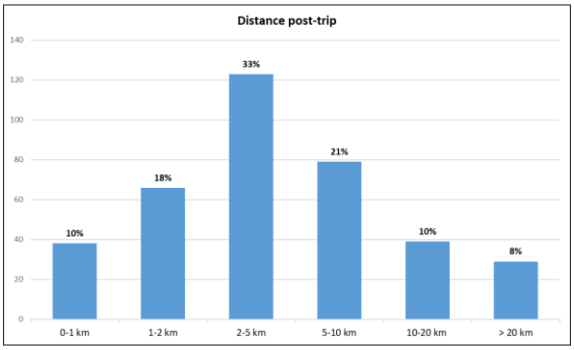

Figure 62: Distance distribution of post-trips

3. Trip length distributions of tour and non-tour trips

Figures 63-70 show the travel times and distances of pre- and post-trips for tour and fourth-and-back trips.

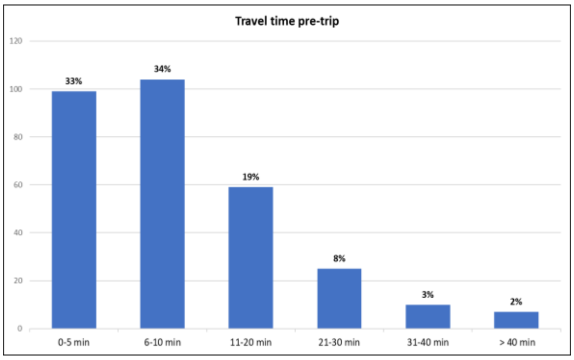

Figure 63: Travel time distribution of non-tour pre-trips

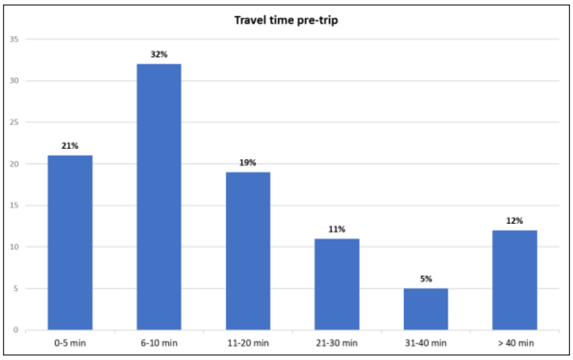

Figure 64: Travel time distribution of tour pre-trips

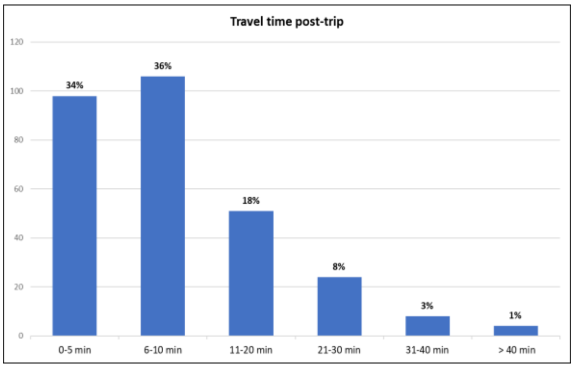

Figure 65: Travel time distribution of non-tour post-trips

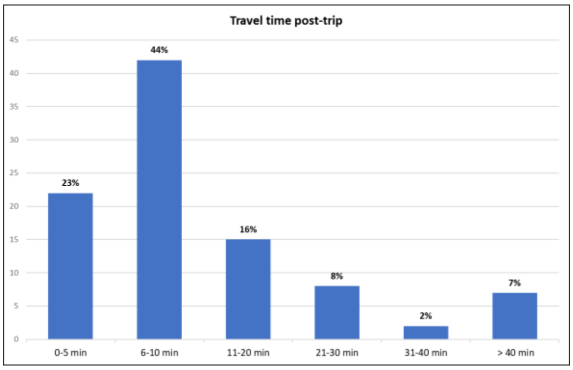

Figure 66: Travel time distribution of tour post-trips

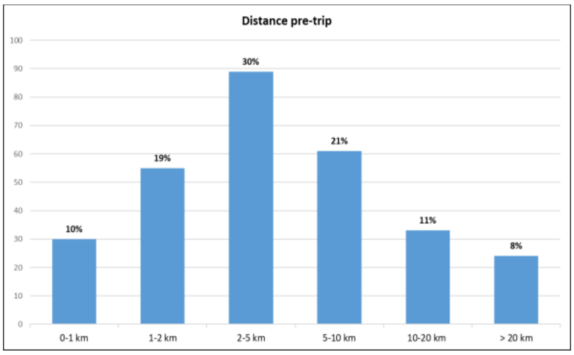

Figure 67: Distance distribution of non-tour pre-trips

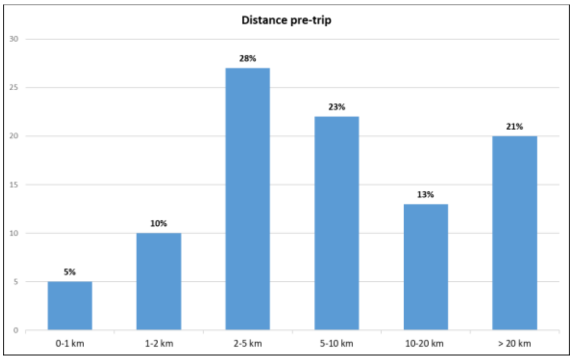

Figure 68: Distance distribution of tour pre-trips

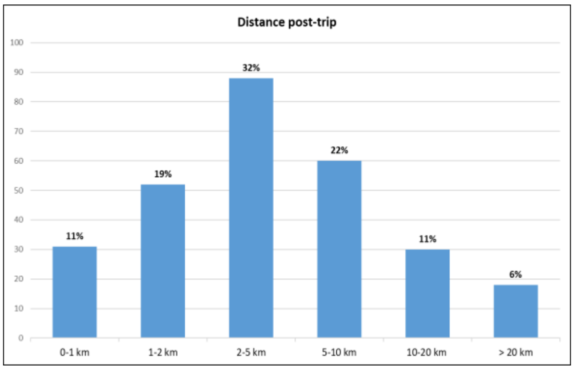

Figure 69: Distance distribution of non-tour post-trips

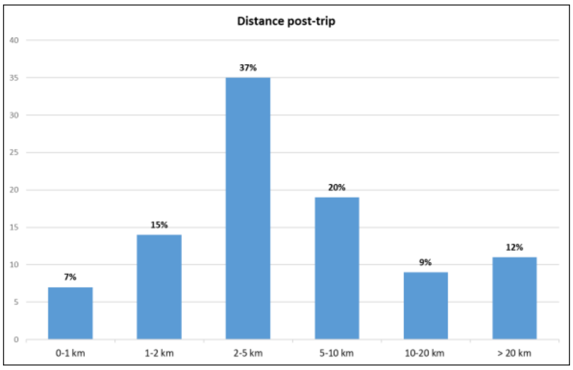

Figure 70: Distance distribution of tour post-trips

Appendix G – Model Results

1. Trip Generation

The results of the Trip Generation step before adjustment of purposes Business and Other in the trip-based model are shown in Table 54.

Table 54: Initial results of Trip Generation step

Purpose	TBM trips	Trip-based model trips	
		Departure	Arrival
Home-Work	55,829,594	64,177,567	59,466,710
Home-Shop	31,670,959	30,117,128	39,394,302
Home-Education	19,930,161	12,671,625	20,794,993
Home-Business	2,411,088	4,732,587	3,589,000
Business	3,733,722	10,248,181	10,248,181
Other	114,260,802	182,195,261	181,152,966
Work-Home	50,099,413	55,600,052	45,838,907
Shop-Home	34,393,400	31,526,142	36,339,022
Education-Home	17,741,032	15,800,502	19,962,301
Business-Home	3,269,447	2,746,009	2,058,947
Total	**333,339,617**	**409,815,054**	**418,845,329**

2. Trip Distribution

a. Intrazonal trips exclusion

Table 55 presents the coefficients used for calculation of intrazonal trips to be excluded from the trip-based model.

Table 55: Coefficients per purpose used for intrazonal trips calculation

Purpose	α	β
Home-Work	9.68	-0.0608
Work-Home	9.68	-0.0608
Home-Shop	3.6	-0.0503
Shop-Home	3.6	-0.0503
Home-Education	5.8	-0.045
Education-Home	5.8	-0.045
Home-Business	10.3	-0.0465
Business-Home	10.3	-0.0465
Business	10.3	-0.0465
Other	6.2	-0.0488

b. Distribution of zone groups

Tables 56-59 presents the trips per purpose of the small zones.

Table 56: Trips per purpose of Trefcenter Venlo zone

Purpose	TBM		Trip-based model	
	Departure	Arrival	Departure	Arrival
Home-Work	334	1,904	408	2,321
Work-Home	1,710	301	1,804	351
Home-Shop	107	2,899	158	2,402
Shop-Home	3,154	121	2,467	225
Home-Education	200	131	88	96
Education-Home	121	185	157	143
Business	104	107	131	131
Home-Business	21	90	30	164
Business-Home	114	26	66	16
Other	1,499	1,601	1,739	1,861
Total	**7,364**	**7,364**	**7,046**	**7,711**

Table 57: Trips per purpose of Maastricht Centrum zone

Purpose	TBM		Trip-based model	
	Departure	Arrival	Departure	Arrival
Home-Work	659	730	636	695
Work-Home	638	566	534	408
Home-Shop	229	313	178	457
Shop-Home	348	287	1,009	276
Home-Education	215	51	120	35
Education-Home	47	174	235	167
Business	47	46	36	36
Home-Business	21	19	35	33
Business-Home	25	29	21	19
Other	924	938	1,170	1,250
Total	**3,153**	**3,153**	**3,975**	**3,374**

Table 58: Trips per purpose of Roermond Centrum zone

Purpose	TBM		Trip-based model	
	Departure	Arrival	Departure	Arrival
Home-Work	1,009	1,944	1,071	2,272
Work-Home	1,742	875	1,702	723
Home-Shop	243	1,202	312	1,564
Shop-Home	1,283	318	3,918	485
Home-Education	284	-	212	-
Education-Home	-	240	-	295
Business	111	119	102	102
Home-Business	41	81	59	150
Business-Home	103	57	62	33
Other	1,669	1,650	2,853	3,187
Total	**6,485**	**6,485**	**10,291**	**8,809**

Table 59: Trips per purpose of Aachen zone

Purpose	TBM		Trip-based model	
	Departure	Arrival	Departure	Arrival
Home-Work	903	1,763	885	2,380
Work-Home	1,574	784	1,569	580
Home-Shop	407	595	252	365
Shop-Home	647	463	907	391
Home-Education	277	639	170	415
Education-Home	580	240	1,756	237
Business	106	123	126	126
Home-Business	41	110	54	205
Business-Home	141	59	78	26
Other	1,948	1,849	1,641	1,613
Total	**6,624**	**6,624**	**7,437**	**6,339**

Tables 60-62 presents the trips per purpose of the middle-sized zones.

Table 60: Trips per purpose of Amsterdam zone

Purpose	TBM		Trip-based model	
	Departure	Arrival	Departure	Arrival
Home-Work	934	34,940	1,841	2,516
Work-Home	29,041	860	2,134	1,235
Home-Shop	89	616	1,166	1,020
Shop-Home	2,892	114	1,959	1,398
Home-Education	301	8,518	1,522	2,108
Education-Home	7,298	262	2,190	2,399
Business	2,636	1,538	1,043	1,042
Home-Business	97	4,593	816	1,209
Business-Home	5,769	116	654	360
Other	18,232	15,734	9,761	9,740
Total	**67,290**	**67,289**	**23,086**	**23,026**

Table 61: Trips per purpose of Utrecht zone

Purpose	TBM		Trip-based model	
	Departure	Arrival	Departure	Arrival
Home-Work	4,961	7,632	485	484
Work-Home	6,520	4,226	407	357
Home-Shop	152	380	345	312
Shop-Home	888	425	505	414
Home-Education	1,106	1,647	456	473
Education-Home	1,435	975	542	718
Business	777	693	199	199
Home-Business	672	671	217	220
Business-Home	883	844	126	107
Other	6,246	6,145	2,729	2,766
Total	**23,639**	**23,639**	**6,012**	**6,051**

Table 62: Trips per purpose of Deventer zone

Purpose	TBM		Trip-based model	
	Departure	Arrival	Departure	Arrival
Home-Work	2,507	2,006	417	419
Work-Home	1,751	2,134	345	323
Home-Shop	224	64	267	218
Shop-Home	164	397	319	320
Home-Education	286	869	322	423
Education-Home	763	249	452	508
Business	225	250	136	136
Home-Business	303	154	146	135
Business-Home	199	378	86	77
Other	2,670	2,590	2,008	2,022
Total	**9,092**	**9,092**	**4,497**	**4,579**

Tables 63-65 presents the trips per purpose of the large zones.

Table 63: Trips per purpose of France 1 zone

Purpose	TBM		Trip-based model	
	Departure	Arrival	Departure	Arrival
Home-Work	-	-	2,292	3,030
Work-Home	-	-	1,821	2,297
Home-Shop	-	-	1,497	1,410
Shop-Home	-	-	1,868	1,821
Home-Education	-	8	635	712
Education-Home	-	-	1,102	1,000
Business	89	-	165	165
Home-Business	-	89	218	211
Business-Home	-	-	108	103
Other	37,743	37,735	5,679	5,700
Total	**37,832**	**37,832**	**15,384**	**16,449**

Table 64: Trips per purpose of Frankfurt zone

Purpose	TBM		Trip-based model	
	Departure	Arrival	Departure	Arrival
Home-Work	138	3,044	436	435
Work-Home	2,520	138	356	275
Home-Shop	2	36	179	171
Shop-Home	303	2	264	218
Home-Education	145	2,983	76	66
Education-Home	2,234	95	116	120
Business	358	252	26	26
Home-Business	25	705	32	31
Business-Home	814	24	17	12
Other	11,962	11,221	702	704
Total	**18,501**	**18,501**	**2,204**	**2,057**

Table 65: Trips per purpose of Berlin zone

Purpose	TBM		Trip-based model	
	Departure	Arrival	Departure	Arrival
Home-Work	4	8	653	590
Work-Home	8	4	486	432
Home-Shop	-	-	282	233
Shop-Home	0	-	359	343
Home-Education	6	45	120	97
Education-Home	33	6	167	188
Business	6	-	36	36
Home-Business	0	6	49	41
Business-Home	1	0	24	19
Other	8,293	8,281	1,075	1,079
Total	**8,351**	**8,351**	**3,250**	**3,059**

c. Old Utrecht distribution

The trips per purpose of Utrecht zone when including the intrazonal trips in the trip-based model can be seen in Table 66. The absolute gap between departures and arrivals are also shown. Table 66 is a result generated when the calculation of the intrazonal trips in the trip-based model was active. However, the final results do not include intrazonal trips, as explained in Section 4.2.2.

Table 66: Trip-based model distribution of Utrecht zone with calculation of intrazonal trips

Purpose	Departure	Arrival	Intrazonal	Gap
Home-Work	48,328	47,178	90,833	2%
Work-Home	11,014	7,572	94,800	31%
Home-Shop	9,867	8,699	58,492	12%
Shop-Home	13,826	3,995	77,161	71%
Home-Education	3,197	4,716	25,103	48%
Education-Home	2,063	12,776	31,806	519%
Business	5,774	5,778	2,757	0.1%
Home-Business	6,337	7,014	3,042	11%
Business-Home	496	360	4,239	27%
Other	111,725	113,215	146,296	1.3%
Total	**212,626**	**211,302**	**534,529**	

3. Modal Split

Table 67 presents the modal split of the trip-based model of the middle-sized and large zones.

Table 67: Modal split of departures and arrivals of trip-based model of middle-sized and large zones

Zone	Departure			Arrival		
	Car	Bicycle	PT	Car	Bicycle	PT
Utrecht	81%	1%	18%	82%	1%	17%
Amsterdam	84%	1%	15%	84%	1%	15%
Deventer	85%	0%	15%	85%	0%	15%
France 1	93%	0%	7%	86%	0%	14%
Frankfurt	85%	0%	15%	85%	0%	15%
Berlin	85%	0%	15%	85%	0%	15%

a. Modal Split per purpose

The modal split per purpose of the analysed zones is shown in Tables 68-76.

Table 68: Modal split per purpose of Maastricht zone

Purpose	TBM			Trip-based model		
	Car	Bicycle	PT	Car	Bicycle	PT
Home-Work	54%	37%	9%	30%	52%	18%
Work-Home	55%	37%	8%	39%	46%	15%
Home-Shop	33%	59%	8%	46%	49%	5%
Shop-Home	31%	60%	9%	65%	31%	4%
Home-Education	18%	57%	25%	31%	60%	9%
Education-Home	18%	57%	26%	38%	47%	15%
Business	71%	26%	3%	86%	12%	2%
Home-Business	88%	9%	3%	88%	10%	2%
Business-Home	82%	15%	3%	86%	12%	1%
Other	47%	45%	8%	56%	39%	5%

Table 69: Modal split per purpose of Roermond zone

Purpose	TBM			Trip-based model		
	Car	Bicycle	PT	Car	Bicycle	PT
Home-Work	67%	22%	11%	43%	38%	19%
Work-Home	67%	22%	11%	53%	31%	16%
Home-Shop	44%	48%	7%	51%	43%	6%
Shop-Home	44%	47%	9%	72%	18%	9%
Home-Education	16%	27%	57%	48%	27%	24%
Education-Home	16%	27%	57%	46%	45%	9%
Business	75%	21%	4%	89%	7%	4%
Home-Business	89%	6%	4%	89%	7%	4%
Business-Home	85%	10%	5%	87%	10%	3%
Other	54%	37%	9%	61%	33%	6%

Table 70: Modal split per purpose of Aachen zone

Purpose	TBM			Trip-based model		
	Car	Bicycle	PT	Car	Bicycle	PT
Home-Work	79%	14%	7%	67%	22%	10%
Work-Home	79%	14%	7%	72%	18%	10%
Home-Shop	81%	15%	4%	81%	15%	4%
Shop-Home	79%	16%	5%	84%	12%	4%
Home-Education	24%	48%	29%	70%	22%	8%
Education-Home	23%	47%	30%	68%	18%	13%
Business	85%	14%	2%	96%	2%	1%
Home-Business	96%	3%	2%	97%	2%	1%
Business-Home	93%	5%	2%	96%	3%	1%
Other	74%	20%	6%	86%	10%	4%

Table 71: Modal split per purpose of Utrecht zone

Purpose	TBM			Trip-based model		
	Car	Bicycle	PT	Car	Bicycle	PT
Home-Work	82%	0%	18%	70%	2%	29%
Work-Home	81%	0%	19%	72%	2%	27%
Home-Shop	63%	0%	36%	85%	3%	12%
Shop-Home	69%	0%	31%	73%	2%	25%
Home-Education	10%	0%	90%	86%	0%	14%
Education-Home	9%	0%	91%	87%	0%	12%
Business	90%	0%	10%	97%	0%	3%
Home-Business	93%	0%	7%	97%	0%	3%
Business-Home	92%	0%	8%	97%	0%	3%
Other	74%	0%	26%	81%	0%	19%

Table 72: Modal split per purpose of Amsterdam zone

Purpose	TBM			Trip-based model		
	Car	Bicycle	PT	Car	Bicycle	PT
Home-Work	77%	0%	23%	68%	1%	31%
Work-Home	77%	0%	23%	70%	1%	29%
Home-Shop	55%	0%	45%	93%	2%	5%
Shop-Home	60%	0%	40%	90%	2%	8%
Home-Education	7%	0%	93%	89%	0%	11%
Education-Home	6%	0%	94%	91%	0%	9%
Business	84%	0%	16%	97%	0%	3%
Home-Business	92%	0%	8%	97%	0%	3%
Business-Home	91%	0%	9%	98%	0%	2%
Other	66%	0%	34%	82%	0%	17%

Table 73: Modal split per purpose of Deventer zone

Purpose	TBM			Trip-based model		
	Car	Bicycle	PT	Car	Bicycle	PT
Home-Work	82%	0%	18%	75%	0%	25%
Work-Home	82%	0%	18%	77%	0%	23%
Home-Shop	66%	0%	34%	96%	0%	4%
Shop-Home	72%	0%	28%	94%	0%	6%
Home-Education	10%	0%	90%	89%	0%	11%
Education-Home	9%	0%	91%	89%	0%	11%
Business	92%	0%	8%	98%	0%	2%
Home-Business	92%	0%	8%	98%	0%	2%
Business-Home	92%	0%	8%	99%	0%	1%
Other	77%	0%	23%	81%	0%	19%

Table 74: Modal split per purpose of France 1 zone

Purpose	TBM			Trip-based model		
	Car	Bicycle	PT	Car	Bicycle	PT
Home-Work	-	-	-	88%	0%	12%
Work-Home	-	-	-	87%	0%	13%
Home-Shop	-	-	-	100%	0%	0%
Shop-Home	-	-	-	100%	0%	0%
Home-Education	100%	0%	0%	100%	0%	0%
Education-Home	-	-	-	100%	0%	0%
Business	100%	0%	0%	100%	0%	0%
Home-Business	100%	0%	0%	100%	0%	0%
Business-Home	-	-	-	100%	0%	0%
Other	88%	0%	12%	81%	0%	19%

Table 75: Modal split per purpose of Frankfurt zone

Purpose	TBM			Trip-based model		
	Car	Bicycle	PT	Car	Bicycle	PT
Home-Work	64%	0%	36%	78%	0%	22%
Work-Home	63%	0%	37%	78%	0%	22%
Home-Shop	59%	0%	41%	100%	0%	0%
Shop-Home	35%	0%	65%	100%	0%	0%
Home-Education	1%	0%	99%	94%	0%	6%
Education-Home	1%	0%	99%	92%	0%	8%
Business	91%	0%	9%	97%	0%	3%
Home-Business	93%	0%	7%	97%	0%	3%
Business-Home	94%	0%	6%	100%	0%	0%
Other	73%	0%	27%	81%	0%	19%

Table 76: Modal split per purpose of Berlin zone

Purpose	TBM			Trip-based model		
	Car	Bicycle	PT	Car	Bicycle	PT
Home-Work	0%	0%	100%	75%	0%	25%
Work-Home	0%	0%	100%	74%	0%	26%
Home-Shop	-	-	-	100%	0%	0%
Shop-Home	0%	0%	100%	100%	0%	0%
Home-Education	3%	0%	97%	94%	0%	6%
Education-Home	0%	0%	100%	100%	0%	0%
Business	86%	0%	14%	100%	0%	0%
Home-Business	75%	0%	25%	100%	0%	0%
Business-Home	0%	0%	100%	100%	0%	0%
Other	85%	0%	15%	82%	0%	18%