Does it work for the weekend?

Examining and implementing adaptations to create a Saturday transport demand model with the provincial model of Noord-Brabant

TIL Thesis

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Examining and implementing adaptations to create a Saturday transport demand model with the provincial model of Noord-Brabant

by

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Preface

Although the subject of this report is about a day in the week which is not about work, the road to this thesis report was everything but relaxed. Be that as it may, this work contains my thesis to obtain a master's degree in Transport, Infrastructure and Logistics which was done from November 2024 until June 2025. The supervision of the Delft University of Technology and Goudappel, allowed me to investigate a broad research gap from which the findings can be applied in practice. In the making of this thesis, the broad scope made the research enjoyable but also insufferable, as i could research many aspects which presented numerous directions for this project. A downside of this is that you can't explore and know everything, forcing you to make decisions you don't want to make yet. Still, i have learned a lot from these kind of challenges which i hope to apply in my future work.

This thesis wouldn't be at this state now without the help of my supervision team. Adam, thanks for your concise feedback which pointed me towards aspects i otherwise would have forgotten. Baiba, thank you for your attentiveness and thoughtful remarks during our meetings and for your detailed comments on my draft reports. Many thanks to Bastiaan and Tony from Goudappel for guiding me through the thesis with weekly meetings and helping me with the development of the model itself. I really enjoyed working with you and Goudappel, many people helped me with practical matters or they were open for a quick chat about the research. Despite the fact that writing a thesis is a great personal endeavour, the environment at Goudappel helped me to learn and grow beyond boundaries that i couldn't have achieved on my own.

Luckily, it didn't feel like i had to it do on my own. I want to thank my family, friends and my girlfriend for their continuous support and for providing a place where i could wind down to release some stress after a week of work. Apart from the question whether weekend days are important for policy development, i know from this time that they remain important to me.

Jochem Van Dijk
The Hague, June 2025

Summary

Workday transport models are extensively used in practice to guide policy development while the more leisure-oriented weekend days are left out of the analysis (Oliver & van Vuren, 2010). This is peculiar, as weekend travel can be as busy as workday travel, or even worse (O'Fallon & Sullivan, 2003). Next to the lack of attention for weekend days in policy development, a transport model for a weekend day is rarely made (R. Liu et al., 2010). This poses the question whether a weekend model is not used as there is no added benefit, or whether a weekend model has not been able to deliver additional benefits or assist in special use cases.

Nevertheless, there is reason to believe that a weekend transport model can assist in a number of policy-related questions. A possible use case can be to improve the estimation of traffic emissions in an area with a weekend model or to better predict traffic situations in locations that regularly attract large crowds, such as sports stadiums or event venues.

This research aims to gain insights in three things, first to develop a preliminary Saturday transport model by adapting an operational transport model. Secondly, to understand Saturday travel patterns so that a clear overview can be made on how differences in travel behaviour should be translated to modelling adaptations. Thirdly, this research wants to uncover what the possible use case and purpose of a Saturday model is. These goals all work towards answering the main research question:

How can the BBMA model be adapted into a preliminary Saturday transport model?

The research uses literature and data-analysis to create to adaptations, that can be used to develop a Saturday transport model. The adaptations are then selected to create two model versions which are compared with each other. These adaptations are made to the BBMA (Brabant Brede Model Aanpak) model, which is the provincial model of Noord-Brabant. Next to this, interviews and additional literature are used to investigate the purpose and use case of a Saturday model.

Analysis results

Weekend travel is fundamentally different from workday travel. This was found in a review of the literature on the differences between work- and weekend day travel. People experience different time constraints due to a lack of work, or tend to go to different places where they perform different activities than on a workday. As a result, there is more variation between and within people in the type and number of activities that are performed. Furthermore, weekend travel is characterised by leisure-oriented trips that are often made together. How people spend their time on workdays also has an effect on time spent in the weekend, work and weekend days are thus dependent on another. This dependency is important to understand the activity pattern of a person in a week.

The interviews showed that there is no clear purpose yet for a Saturday model as it is uncertain how a Saturday should be regarded in policy development in comparison with workdays. However, there are use cases for a Saturday model in which such a model can have a purpose. For example, to compare traffic flows between work- and weekend days. These use cases advocate for the development of a basic Saturday model, both to assess its potential contribution to policy development and to provide a foundation that can be adapted for specific applications.

Modelling approaches for a weekend day or non-work trip purposes were lacking in the literature, or they were not applicable to the setup of the BBMA model. This made it difficult to asses how a Saturday model should be developed. Nonetheless, the literature shows that while weekend models can be developed, their development is constrained by data availability or the required effort to make such a model. Furthermore, research shows that the modelling of non-work trip purposes can mainly be improved by using data with a higher quality instead of focusing on advanced modelling techniques. Next to this, the conventional method for developing a transport model was deemed to be suitable to

model a Saturday. This is in line with the model setup of the BBMA model, although an Activity Based model can possibly better portray Saturday travel behaviour.

Due to the lack of a clear starting point for model development, an assessment was made on how the differences in travel behaviour could be turned into modelling adaptations to adapt a workday model. An overview of these differences and the adaptation that is required for a Saturday model is shown in table 1. Next to this, the adaptations are ranked on the effort required for implementation and the perceived benefit of the adaptation, from which two of the adaptations are identified as necessary adaptations for a Saturday model.

Table 1: Overview of characteristic differences in work- an weekend day travel, with the corresponding adaptation and effort/benefit

	Characteristics	Adaptation	Effort - Benefit
C1*	Different trip purposes have a higher share in the weekend.	Use different trip purposes in a weekend day model	Medium - High
C2*	Saturdays and Sundays show different travel behaviour	Model Saturday and Sunday separately	Low - High
C3	There is more difference in activity patterns between persons.	Incorporate different variables or classifications to show differences in travel behaviour in the model	High - Medium
C4	The weekend has different constraints/obligations and therefore a higher temporal variability.	Model different time periods or show the possible bandwidth of the results	Low - Low
C5	Spatial variability of travel is higher, people tend to explore new activities/destinations.	Incorporate the possible destinations per trip purpose in the trip generation or trip distribution step of the model.	Medium - High
C6	Larger difference in trip-chaining behaviour between people	Consider a tour-based model, if this is required.	-
C7	The choice for an activity is more important than the choice for a mode of transport.	Asses whether the model structure is sufficient to model the dependency between activity choice, destination choice, mode choice and route choice in the model.	High - Low
C8	There is more joint travel in the weekend, especially within a household	Include variables that reflect joint travel or update the attribute in the model.	Low - Low
C9	Mode choice is different	Re-estimate mode choice parameters	Medium - High
C10	Time of day of travel is different	Model different time-periods.	Low - Low
C11	The value of travel time is different	Re-estimate the VOT and other required attributes for a weekend day model.	Medium - Low
C12	External effects like road works, events or seasonal variations can all have a different effect on the choice to travel in the weekend as there are less constraints to travel.	Consider a certain bandwidth in the models results or a standard set of variants which reflect these external factors.	Medium - Low

**necessary adaptation for a Saturday model*

Model adaptations and results

Two Saturday model versions were created. The first, model A2, was based on adaptations C1, C2 and C9. These were chosen as they are necessary adaptations for a basic Saturday model. The second model version, which was B2, is based on adaptation C5 and employs three variables to better predict the destinations for shopping, social-recreational and sport trips. This was done because this adaptation can have a high benefit in the realism of the model, according to the effort/benefit ranking. Secondly, the adaptation is a direct improvement in model A2, as it was found that there was little difference between the trip purposes in the explanatory variables.

The results show that although the developed model performs well on a regional level, the model is not able to correctly capture differences in trip purpose between municipalities when assessed in more detail. Despite this, the internal validation of the model shows that a Saturday model can be developed using the same methodology as the workday model in this research, apart from the results on public transport which are unrealistic. The analysis of the results enables a detailed picture of how the developed model versions work, revealing that Saturday model A2 is a simplistic portrayal of travel behaviour on Saturday. Consequently, Saturday model B2 is not able to be a direct improvement upon this.

Conclusion and recommendations

The main conclusion of this research is that an existing workday model can be adapted by using different trip purposes as well as Saturday travel data to create a preliminary Saturday transport model. The main changes in the model are required in the trip generation step, while other adaptations can be made to increase the realism and functionality of the model in it's ability to portray average Saturday travel behaviour.

The research thereby creates a starting point for the development of a basic Saturday model by proposing a set of adaptations for further development. It should however be considered that an Activity-Based model can portray Saturday travel behaviour in a more realistic way than an aggregate approach but both are suitable to create a Saturday model. No clearly defined purpose for a Saturday model was found in this research. Despite that, several use cases were identified which support the purpose of a basic Saturday model so that it can be adapted for a specific use case.

The findings in this research pave the way for research and discussions on how Saturday travel behaviour should be regarded in the development and maintenance of transport systems. It is recommended to research how a Saturday should be regarded in policy development while simultaneously developing a Saturday model that can assist policy makers. Furthermore, several recommendations are made on technical aspects in development of the model.

Contents

1 Introduction

Travel patterns in the weekend are different from patterns observed on a workday (Zhong et al., 2008). Not only is this reflected in the different travel motives that people have in the weekend, such as visiting friends, taking part in a recreational activity or discretionary shopping, weekend travel also takes place at different times of the day and in different locations than on a workday (R. Liu et al., 2010). For instance, trips are made later on the day as there are no time constraints or more flexible schedules. Next to that, people are more likely to go to shopping malls, entertainment venues or city centres in comparison with a regular workday. Additionally, the choice for a mode of transport can be different in the weekend as more people travel together. People tend to use a car rather than public transport (Ho & Mulley, 2013). Altogether, these decisions shape the different travel patterns that can be observed in the weekend (Raux et al., 2016).

The diverse travel patterns in the weekend also have an effect on peak traffic, which can be as busy or busier than on a workday (O'Fallon & Sullivan, 2003). This can be explained by a lot of different factors. In the weekend, many people tend to go to a city centre to go shopping or to attend an event. This can create local traffic problems but it can also have an effect on a regional level. Seasonal factors also play a role (Yang et al., 2016). In the summer, beaches or parks often see heavy congestion as they attract a lot of visitors (Marvasti, 2013). Additionally, large-scale events such as concerts or sports games can further intensify traffic. All these factors highlight the complexity of weekend travel patterns, and how they can contribute to large traffic volumes.

While traffic problems arise in the weekend, existing transport models have mainly been developed for workdays, leaving weekend days out of the focus (Oliver & van Vuren, 2010). It's possible that weekend travel didn't cause urgent traffic problems since a large emphasis has always been on optimizing the road network for workday travel. Workday transport models are typically focused at peak hours, aiming to alleviate congestion (Naess et al., 2012). A large share of these peaks constitutes of work or education related travel, while other travel motives are less present. Logically, these models became good at estimating peak traffic flow on workdays as this was where most of the problems occurred. As a result, other travel motives or weekend days were less important to model accurately.

An effort has been made to develop weekend models but to the author's knowledge, there are no complete transport models which model a weekend day. Simplified approaches were used to obtain results, but a model which considers weekend travel behaviour specifically is missing. Two of these approaches are described here, Oliver and van Vuren, 2010 used off-peak weekday traffic data and applied factors to obtain traffic intensities of a regular Saturday. In R. Liu et al., 2010, a mode choice model was developed to estimate weekend travel in New Jersey. Although both models are useful for their application, they lack the behavioural background of a complete transport model, making the models unsuitable for other analyses such as investigating the number of people that go shopping in a city centre.

Having a complete transport model is not only a nice-to-have but it can provide additional insights into weekend travel, support better planning for infrastructure or mobility-related policies. First of all, the outcome of a weekend model can enhance the understanding of travel patterns which are unique to the weekend. For example, a weekend model can be used to analyse current or future travel times in an area. This information can be used to predict the accessibility of a city centre which can be part of an analysis into the welfare of an area. Additionally, a transport model can be used to measure the environmental impacts of traffic in the weekend. These kinds of analysis are crucial in current decision-making processes for projects which concern the environment (McCormick et al., 2013). Additionally a transport model can help to explore how environmentally friendly modes of transportation can be encouraged in an area. A comprehensive weekend model can thus aid municipalities or transport planners in a different set of challenges than the current workday models.

Building on the need for a dedicated weekend model, this research will try to develop a Saturday transport demand model that can accurately estimate travel patterns on a Saturday. As a result, a Sunday model is not developed in this research as Saturday and Sunday show important differences in travel patterns. This research will focus on developing a Saturday model but differences in the weekend are included in the analysis. The research will be done at the company Goudappel, which develop transport models and advise governments on transport and mobility issues. The company is interested in gaining a better understanding of travel motives in general, which thus includes the Saturday. With this new knowledge, they can better support governments to make decisions in spatial development or traffic management.

The rest of this chapter will outline the research goal, enumerate and explain the research questions, show the structure of the report, elaborate on the scientific and societal relevance of this research and lastly the scope and limitations of the research are discussed.

Research Questions and Goal

The goal of this research is twofold, first to develop a preliminary Saturday transport model by adapting an operational transport model, the provincial model for Noord-Brabant, by using Saturday travel data. A preliminary model is a model capable of running and evaluating basic scenarios which will produce sensible results. Secondly, this research wants to understand Saturday travel patterns to create a clear overview on how the model should differ from a workday model. This goal is reflected in the main research question:

How can the BBMA model be adapted into a preliminary Saturday transport model?

To achieve this research goal, the main research question is answered by the following sub-questions:

1. What are travel patterns and characteristics of travel on a Saturday in comparison with a regular workday and Sunday?
2. What are existing modelling approaches for weekend models and non-work trip purposes and can these be used to adapt the BBMA model?
3. What is the use-case and purpose of a Saturday model for governments and traffic planners?
4. How does the developed model perform when compared to travel data on a Saturday?

Research methodology and thesis outline

This section provides the outline of this thesis and explains how the sub questions form the methodological steps of this research. A visualization of the research process can be seen in figure 1.1. In this figure the chapter numbers are shown with their main methodology. For example, in Chapter 4, the main method will be a data-analysis. The arrows indicate how the chapters relate to each other. This is because the information that is obtained in a chapter is used as a starting point for another chapter, illustrating the research process.

The aim of the first sub question is to discover the differences between workday, Saturday and Sunday travel. This is first addressed in Chapter 2 where literature on travel behaviour is reviewed, which discusses differences between work- or weekend days. The expected outcome of this chapter is a list

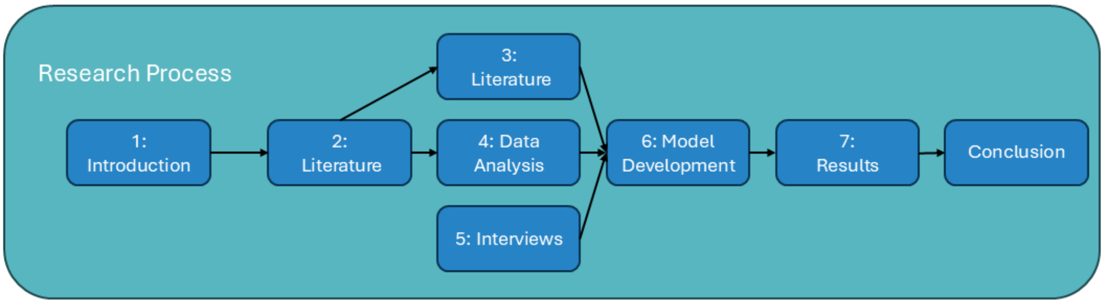


Figure 1.1: Research process with the corresponding method per chapter

with the key differences in work- and weekend travel. This is a crucial component of the research that is used in Chapter 3, to define which modelling adaptations are required to adapt a workday model, based on the differences in travel behaviour. Secondly, the differences can be used in Chapter 4 to guide the data analysis into differences in work- and weekend travel. That is because Chapter 4 aims to answer sub-question 1 as well, by analysing travel data from the ODiN survey, to come up with a set of differences. Next to this, the data analysis can be used for practical analysis of the data in the development of the model.

The second sub question explores what a suitable starting point point is for adapting a workday model into a Saturday model, in Chapter 2. This is firstly done by reviewing existing modelling approaches and determining if these are suitable to create a Saturday model. Secondly, this research will determine how the key differences in travel behaviour from Chapter 3 can be adapted into a Saturday transport model, based on the existing modelling approaches. The constructed adaptations will then be ranked based on their functionality to transform a workday model into a Saturday model, which can act as a direct input for the model development in Chapter 6.

An additional research goal is formulated with the third research question. The aim of this question is to obtain use cases and the possible purpose of a Saturday model in Chapter 5. As the introduction mentioned that there is a certain need for a weekend model, it's important to investigate if there are use cases in which a Saturday model has a clear purpose. The main method used to answer this sub question is to hold interviews with municipalities and mobility experts. Additionally relevant literature which discusses the use case and purpose of a weekend model will be reviewed in Chapter 5. The outcome of the interviews and the literature can be used to steer the model development part of this research or to define use cases and the purpose of a Saturday model.

The model development part of this research will be described in Chapter 6, which in turn answers the main research question of this research. This is done by selecting a set of adaptations that transform the workday model into a Saturday model, within the scope of the BBMA model. This will be an iterative process to improve the model stepwise, so that the impact of each adaptation can be reflected in the results.

Lastly, the fourth sub question is answered in Chapter 7, which aims to validate the developed Saturday model with travel data. The model will be validated on a regional scale, on results like the modal split or trip purpose distribution. This is also done on smaller scale levels to investigate how the model tackles travel demand. Additionally, the results of the model allow a reflection on the overall use case and purpose of a Saturday model.

Scope and limitations of the study

As this research encompasses a broad topic, decisions about the scope should be taken. A first decision is to focus on the Saturday, instead of trying to model both weekend days in one model. This is done as a Saturday has more diverse travel behaviour and Saturdays are generally busier than Sundays (R. Liu et al., 2010). Additionally, modelling the Saturday separately delivers a model which is representative of one day, instead of a combined model that can't show the intricacies of a Saturday or Sunday. Next to this, developing a Saturday model can give a head start for the development of a Sunday model. Because of this reason, the Sunday is still included in the analysis of this research.

Both passenger and freight travel are considered in the estimation of transport models. However, passenger travel is a significantly larger part of Saturday travel. Freight travel, on the other hand is concentrated on weekdays and analysing that to correctly include freight travel in the model, requires additional data sources next to ODiN and the NVP data. A small analysis of traffic intensity data showed that the share of freight traffic is at least 50 % lower on weekend days (NDW, 2025). As a result, freight travel is excluded from this research.

To estimate a transport model, a lot of data is required. Usually, the data of multiple workdays is used to estimate a regular workday. For a Saturday, this is not possible as only the Saturday is of interest. On top of that, national holidays are usually not representative for a regular Saturday, so this data can't be used. Less data is thus available to estimate a model, therefore the regional model of Noord-Brabant is chosen in this research, which is also called the BBMA (Brabant Brede Model Aanpak). This is done as there is probably more data on an entire region than on a specific city, making it more likely that a model can be estimated. As a result of this decision, the research into modelling approaches will be reduced to approaches that fit within the modelling framework of the BBMA. The BBMA is a trip-based model, which means that tour-based modelling approaches do not fit in this research. Nevertheless, ideas from these modelling approaches could be included in the research.

Scientific and societal relevance
The scientific significance of this study is that a preliminary Saturday transport model will be developed. To the author's knowledge this will be the first complete transport model that models a Saturday. It is possible that a complete weekend model has been developed, but these results are not published or they might be found in grey literature. With a complete model, it is meant that the model will employ all the steps in the four-step modelling approach, later explained in section 3.3. This research will also investigate how Saturday travel patterns are different from travel patterns on a workday or Sunday. In the literature this is an understudied topic and this research will contribute to that by providing an overview of Saturday travel patterns. This knowledge can also be used to make better transport models for workdays. With 'better', it is meant that the model has a more substantial behavioural background of travel patterns on a Saturday. This can be beneficial for workday models as well, as knowing how recreational trips should be modelled on a Saturday, can enhance the modelling of these trips in workday models. Additionally, this study will create an overview of the literature on Weekend transport demand models, which can be used as a starting point for future research.

The societal relevance of this research is that a Saturday transport model can be used to investigate or solve traffic problems on a Saturday. Depending on the scale of the model, an analysis can be done with the model to improve the liveability or accessibility of the research area. Furthermore, insights from the data analysis can help policy makers to better understand the intricacies of Saturday travel, which can improve their decisions, which can in turn benefit society.

2 Differences in work and weekend travel behaviour

This chapter sets out to discover how travel behaviour is different on weekend days when compared to workdays. Not only is the difference with the weekend investigated, but also between a Saturday and Sunday. As this is a broad difference to investigate, the literature review will follow an exploratory or iterative process that sets out to find the main differences but it will not be an all-encompassing overview which contains the main aspects of travel behaviour. This is done to partially answer the following sub-question:

1. What are travel patterns and characteristics of travel on a Saturday in comparison with a regular workday and Sunday?

The outcome of this chapter will be used to get an overview of the main differences between work and weekend travel and to act as a knowledge basis for the rest of the research. This overview will take shape in the form of a list of characteristics about the key differences between work and weekend day travel that were found in this literature review. Furthermore, this list will be used in chapter 3 to asses how the differences can be assimilated into model adaptations within a trip-based four-step transport model. The outcomes off this chapter will be further used to shape the data analysis in chapter 4. Key insights or knowledge gaps can be further researched with the available data. Finally, the information that is collected in this chapter can act as background information on differences in travel patterns for the interviews in chapter 5.

The structure of the chapter is the following, first the review methodology will be presented in section 2.1. The literature then starts by discussing differences in travel behaviour with aggregate indicators such as trip purpose in section 2.2. Section 2.3 will then discuss differences in the variability of travel and why this is a relevant aspect of travel behaviour. After that, section 2.4 will discuss differences in time use between work- and weekend days. Section 2.5 and 2.6 then discuss how joint travel is different in the weekend and how external effects can influence travel behaviour in the weekend. The chapter ends by presenting an overview of the differences that were found in section 2.7.

2.1. Review methodology

This section presents the review methodology that is used in this Chapter. Multiple search engines were used in the research process, which include Scopus, the Web of Science and Google Scholar. Scopus and the Web of Science are databases for journals which publish peer-reviewed research from all over the world. These search engines were used to find key papers for this research. Additionally Google Scholar was used to quickly search for relevant papers or grey literature which is also relevant for this research. Search keywords were used in combination with each other to obtain relevant papers. An example of a search term is:*""Trip purpose" AND "Weekend"*. Table 2.1 also provides an overview of all the search terms that were used. They have been categorised in two groups to create an overview.

Most of the times, a keyword from both categories is combined either with an AND or OR operator. This delivered specific results with the keywords that were used, as it was found that using more than two keywords delivered too little results.

Table 2.1: Used search keywords in general categories

Category	Keyword
Travel behaviour	”trip purpose”, ”trip pattern”, ”destination choice”, ”spatial variability”, ”mode choice”, ”travel demand”, ”land-use”, ”activity pattern”, ”intra-household interaction”, ”joint travel”, ”time-use”, ”travel behaviour”.
Weekend travel	”weekend”, ”workday”, ”Saturday”, ”Sunday”, ”leisure travel”, ”non-work”, ”discretionary travel”, ”maintenance travel”, ”day-to-day variability”, ”shopping”

In some cases, it is hard to find relevant papers because different keywords or terminology is used for a subject. A suitable technique to still find relevant papers, is forwards and backwards snowballing. With this method, interesting sources are found by looking at the references and citations of an important paper in the literature.

When searching for relevant papers, a paper was selected by reading through the abstract or by looking through the paper to find any relevant information. The paper was then stored in Zotero. This is a program to organize information into different groups and notes can be made to summarize the key findings of a paper. In a later stage, all the sources were reviewed and filtered. The criteria for the filtering were different for papers about travel behaviour or transport models. Papers about travel behaviour were discarded if they didn’t provide information about the weekend, recreational trip purposes or if the papers didn’t provide core information about a theory of travel behaviour which was relevant for the research. This resulted in a total of 35 papers which were reviewed for this Chapter, from which 20 were used in the running text. Papers that weren’t used were too detailed or they didn’t describe a difference between work- or weekend travel at a sufficient level.

2.2. Travel Patterns

This first section will discuss general differences between work- and weekend travel that were found in the literature that describe travel behaviour at an aggregate level. This provides a first overview for the rest of this chapter. Topics that will be discussed are trip purpose, time of day of travel, mode choice and the value of time.

2.2.1. Trip purposes in the weekend

The average number of trips that are made per day per person differs slightly between workdays and weekend days but there is more variation between trip purposes (Lockwood et al., 2005). Weekday travel is usually characterized by travel to work, school or business related trips. Non-work travel purposes do form a substantial share of travel on weekdays but this share is higher on weekend days, as there is little work-related travel. An overview of the average number of trips per purpose can be seen in 2.2. This table was adapted from (Raux et al., 2016) and the results are from a seven-day travel survey in the city of Ghent.

When looking at the single trip purposes in the table, some interesting observations can be made. On workdays, more trips are made to drop people off or to pick them up. Presumably because children need to be brought to school on weekdays, whereas the weekend has less constraints for this particular trip purpose. Next to that, people spent more time on personal business on the weekdays, this is because for example dentists or hairdressers are open on weekdays, imposing people to do these activities on weekdays. This highlights the difference between work and weekend days.

Differences in trip frequency arise between Saturday and Sunday. Less trips are home-bound on a Sunday, meaning that on average, less trips are made. Additionally, daily and long-term shopping show a considerable difference with Saturday. On the other hand, more recreational trips are made on a Saturday and visiting family or friends is done as often as on a Saturday. This indicates that Sunday is more leisure-oriented and people prefer to do less out-of-home activities, to prepare for the coming

Table 2.2: Average number of trips per trip purpose on different days. Adapted from: (Raux et al., 2016)

Activity Purpose	Workday	Saturday	Sunday
Home	1.5	1.45	1.18
Work	0.53	0.1	0.04
School	0.16	0.01	0.01
Having a meal	0.08	0.12	0.09
Daily shopping	0.38	0.53	0.22
Long-term shopping	0.12	0.25	0.05
Personal business	0.17	0.09	0.05
Visting family or friends	0.21	0.38	0.38
Walking, riding, etc.	0.1	0.18	0.26
Leisure, sport, culture etc.	0.19	0.37	0.33
Dropp off/ pick up	0.34	0.22	0.14
Other	0.2	0.22	0.15

workdays (Bhat & Gossen, 2004). The Saturday is more so-called maintenance tasks. These are tasks that have to be done, such as grocery shopping, so that people are able to cook a meal at home. The task doesn't immediately fulfil a certain need, but it is required for future needs or duties. The opposite of maintenance activities is a discretionary one. These are activities that you love to do, or you do them as you see fit. Too conclude, Saturday and Sunday show different travel patterns in terms of trip purpose and trip frequency from a workday.

2.2.2. Differences in time of day of travel

The time at which people choose to travel can differ for work- and weekend days due to the different time constraints that people experience. Figure 2.1 demonstrates this difference. The figure was adapted from Lockwood et al., 2005 which conducted a two-day travel survey in the San Francisco Bay area with over 15.000 individuals. A clear morning and evening peak are visible for the weekdays but both weekend days don't show such extreme peaks. In the morning, less trips were made than on weekdays but the time period from 10:00 AM to 3:00 PM shows that more trips were made.

In another analysis by Zhong et al., 2008, the social-recreational and shopping trip purposes are the trip purposes that follow the time of day pattern that can be seen in figure 2.1 on weekend days. While trip purposes like work and school cause the morning and evening peaks on weekdays. These observations are in line with the expectations that weekend travel starts later and that there is no distinguishable peak in the day, when compared to workday travel.

2.2.3. Mode Choice in the weekend

The choice for a mode of transport is a decision which is made differently on weekend days than on workdays for non-work trip purposes. The choice for an activity is made before a mode of transport and this choice is amplified by different joint travel arrangements in the weekend (Ho & Mulley, 2013). The car is the most convenient mode of transport for joint travel and therefore it is chosen more in the weekend. This is confirmed in different studies which showed that the car is used more than other modes of transport but the car also has higher car occupancy rates in the weekend than on workdays (Lockwood et al., 2005).

Consequently, public transport is used less in the weekend. Work and education are the main trip purposes which utilise public transport on weekdays but these trips are not made regularly in the weekend (Yang et al., 2016). In addition to this, public transport is mainly used in the weekend by people who don't have a car or for specific trips for which public transport is convenient, such as an event or football match. Additionally, active modes such as cycling and walking have a lower share in the weekend. The mode is used more for active recreational purposes such as sports but less for purposes such as shopping or recreation in the weekend. Interestingly, people are less likely to walk to the supermarket in the weekend, while they did so on a workday (Lockwood et al., 2005). Ultimately, these differences show that mode choice is driven by the different activities that are performed in the weekend and that

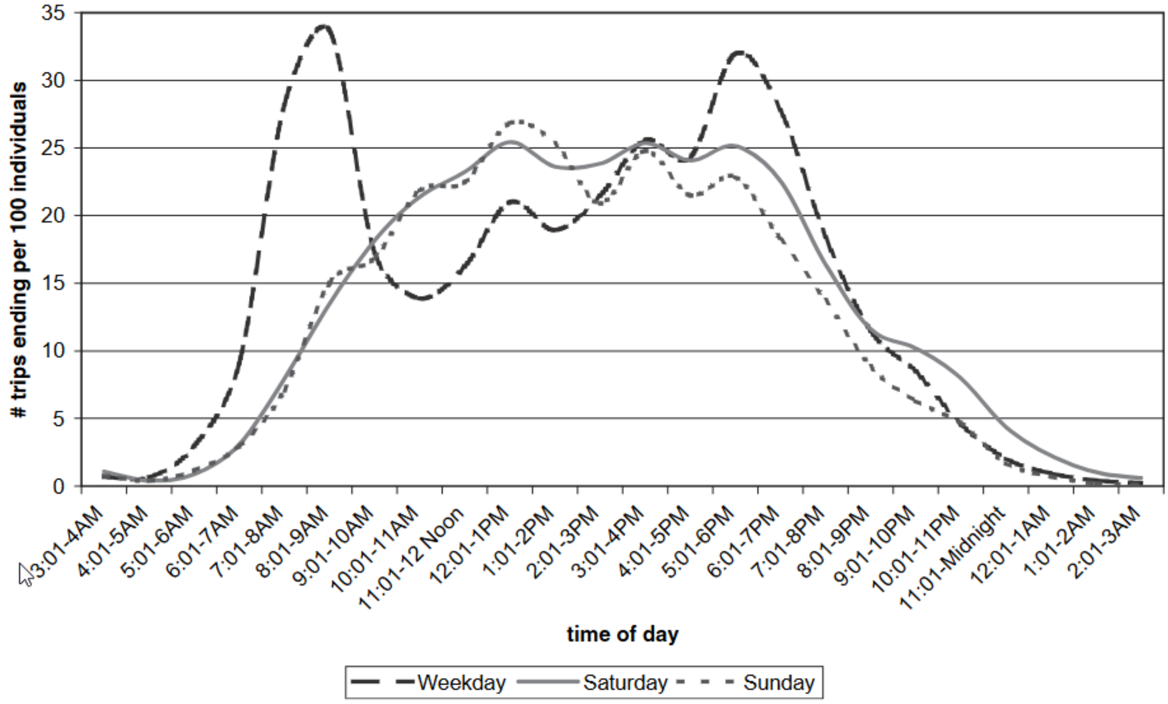


Figure 2.1: Time of day of travel, adapted from (Lockwood et al., 2005)

the flexible nature of weekend travel also translates to mode choice.

2.2.4. Value of travel time

The value of travel time (VoT) is a variable which is widely used in policy development to assign a monetary value to the travel time savings achieved through a new infrastructural project or policy. The VoT is used to calculate the monetary gain from a project or it is used to express how people value their travel time. Due to the differences between work- and weekend days, it is likely that the VoT will be different in the weekend. Prasetyo et al., 2003 hypothesised that the VoT is higher in Japan on weekend days because people put more value in social activities which can't be done on weekdays and time is limited on the weekend. Therefore the VoT should be higher as people want to spend less time travelling and more time on activities. Ho and Mulley, 2013, confirmed that the VoT was higher in weekends in Australia. Alternatively, it was found that the scheduling of social activities is not affected by the travel time to this activity (Habib, 2011). From this, it can be inferred that the VoT can differ per country and that it's therefore useful to use VoT values that were obtained in the Netherlands, such as presented in KIM, 2023. This study presents VoT values for the Netherlands but the values are estimated for a limited number of trip purposes, which are typically present in a workday. More effort is needed to estimate the VoT on weekend days and on weekend-related trip purposes.

2.3. Differences in variability of travel

The previous section has shown how travel behaviour is different on an aggregate level between work and weekend days. This section will further dive into the variability of travel which is a crucial aspect of travel behaviour, as it defines how travel is different at an individual level (Jones & Clarke, 1988). Variability of travel can be defined in different ways, this section will discuss the variability between persons, e.g. how does the travel behaviour from 2 individuals differ on a day, and the within person variability, which is the variability of travel of an individual. In other words, how does the travel behaviour of an individual vary over a day or a week. Both measures are useful to understand travel behaviour and it allows a researcher to identify habitual patterns. The between person variability, or inter-personal variability, can be used to identify for example how the number of recreational trips that are made differs between persons on a weekend day or to identify the different activity start times between persons. The within person variability, or intra-personal variability, can identify how the number of recreational activities differs within a person on each day of the week or how the destination of a shopping trip differs within a person.

These examples show that variability can be measured for different aspects of travel behaviour. This section will discuss the temporal variability of travel, spatial variability and the variability in trip-chaining.

2.3.1. Temporal variability of travel

Trip frequency is a good variable to look at aggregate trip-making behaviour per day but travel patterns follow a weekly routine or they are different per person. Within this weekly routine, travel behaviour is more irregular on weekends than on weekdays (Schlich et al., 2004), or there is more temporal variability. People have more free time to spent in the weekend, so they regularly choose different activities than on a weekday.

This is also called intra-personal variability, or how much travel behaviour differs within a person. For example, for work purposes there is less intra-personal variability, while for recreational purposes there is more variability within persons because people prefer different recreational activities, while work activities are the same. When an entire week is considered, the intra-personal variability is higher than the inter-personal variability (Raux et al., 2016). This means that there is a higher difference of activities within a person for an entire week, than between persons. So, two different persons might perform 10 different activities in a week, but they have both performed 10 activities. This effect is different in the weekend, as the inter-person variability is then higher than the intra-person variability. This means that two different persons can perform a different type of activities, but also a different number of activities in the weekend. As an example, one person might perform 5 different activities on a weekend day, which differ in activity type. While another person just performs one activity. To conclude, the temporal variability is larger in the weekend and it's important to consider that this variability is based on both the habitual and random aspects of travel behaviour.

2.3.2. Spatial variability of travel

Spatial variability of travel in the weekend is characterised by different types of destinations and travel time than weekday travel. First of all, work-related travel is bound to the same destination, while recreational trips rarely go to the the same destination in the same week (Schlich et al., 2004). The day with the highest variety of spatial destinations is the Sunday, according to Raux et al., 2016. This can be explained by the high share of recreational trips on Sundays. Interestingly, Monday and Tuesday had a higher spatial variety than Saturday. Indicating that people also tend to explore new destinations on workdays and that the Saturday is used for regular activities.

Next to this variety, travel time and distance can be longer for social or recreational trips than for work trips. People tend to minimise their time spent on commuting to work while other kinds of trips can be longer (Agarwal, 2004). These longer trips can be explained by the spread of social networks of people. Indicating that people want to make the trip and the distance is less important for the decision to travel.

2.3.3. Variability in Trip-chaining

The sequence of activities that people perform out of home are a crucial part of understanding travel behaviour. Some people might prefer to go shopping straight after work, while others prefer to go home at first. The type of activities that are sequenced is also called trip chaining. As was presented earlier, the number and type of activities that people do in the weekend differs more between persons than within a person. This is also reflected in people's trip chaining behaviour in the weekend (Raux et al., 2016). Some people will combine a lot of different activities on one day, while other's don't. This difference is thus larger in the weekend than on workdays.

Trip-chaining behaviour in the weekend is also dependent on trip-chaining on workdays (Islam & Habib, 2012). People with long work days tend to make simple trip chains on workdays while they do make complex chains in the weekend. This comes down to the time allocation of people and the constraints that they have to meet on work- or weekend days. Another interesting difference on trip-chaining in the weekend is that the choice for the activity sequence is made before the choice for a mode of transport (Islam & Habib, 2012). For non-work trip chains on workdays, the opposite is true. A logical explanation is that the car availability in households is different in weekends and that therefore, mode choice is less important. The difference also highlights that the choice for the type of activity is more important, as this can be more flexible.

Because of the larger differences between people in the weekend, it's harder to conclude whether people are prone to making more complex trip-chains in the weekend, than on workdays. Socio-demographics can partly explain this variation between persons, such as that highly educated people are more likely to make complex non-work trip chains in the weekend (Islam & Habib, 2012). This is an interesting observation but there are more factors that determine whether someone makes a complex trip-chain than education level. Consequently, using socio-demographics to derive a conclusion about complex trip-chaining, is based on a generalised view of travel behaviour, but these factors can not fully explain the day-to-day variability of travel (Raux et al., 2016). These factors lie in the habitual and random aspect of travel and the choice for an activity is not bound to a specific day of the week. Therefore, the literature is not able to conclude whether trip-chaining behaviour is more complex in the weekend in general, but it does indicate that the variability is larger.

2.4. Dependencies of work- and weekend days in time use

Time use of people differs between work-and weekend days but it is also dependent on each other. This means that a shopping activity which is performed at the start of the week, is likely to influence the propensity that another shopping trip is made in that week. First, the evolution of time use is discussed to show how this impacted the time spent on recreational activities. Secondly, the way in which disruptive events affect time use is discussed to show that time use is perceptive to such events. Thirdly, the importance of in-home activities is related to time use in the weekend and that it's important to consider in-home activities in the activity modelling of a person. Lastly, differences in time use are discussed between work- and weekend days.

While some old habits stay the same, people have developed new routines to spend their time. One of the most notable impacts on the time budget of people has been the reduction in working hours from 60 to 40 hours or less in the last century. Giving people more free time to do leisure activities. Additionally, more people are working from home, or people prefer to work in the evening (Schlich et al., 2004), which changes the way in which we use our time. This indicates that more time can be spend on non-work related activities, or it has become easier to combine activities on a workday.

Next to the time budget, the variety on the type of leisure activities has changed. Schlich et al., 2004 indicates that recreational activities such as sports have become more specialized. It is normalized that people choose different hobby's, instead of joining the local soccer club. Additionally, leisure time is associated a lot with social time. Nearly 50% of leisure trips were a social activity (Schlich et al., 2004). While some of these developments have changed slowly, some developments can have a larger impact on the time use of people than others.

Especially the outbreak of Covid-19 brought changes in time use, which had a particular impact on travel patterns as well (de Palma et al., 2022). Some of these changes in time use, have had a lasting effect on travel behaviour, while others have diminished. As an example, working from home is now normalized, but the use of the car has returned to the level from before Covid-19. A side-effect of this is that most people work out-of-home on the same day, resulting in more disturbances on these days. Another example is that more people went outside for a walk, during covid, and they kept on doing this (CBS, 2024a). Additionally, people planned more out-of-home recreational activities after Covid, to compensate for the lack of these activities. Which of these changes will become permanent is unknown yet, but it is clear that disruptive events can cause a change in time use which affects travel behaviour.

Changes in time use are not only limited to out-of-home activities. In the weekend, more activities take place at home than outside (Ellegård & Vilhelmson, 2004). These activities can be household tasks, preparing food, watching TV or having dinner. These activities can of course be described as being home but it is important to acknowledge that the type of activities that are performed in-home have an effect on the activities that are performed out-of-home. It can be that online shopping causes a reduction in the number of shopping trips that people make, causing people to save their time for other activities. Changes in at-home activities are thus relevant indicators for how travel patterns can change but it's also relevant to consider how different activities are divided over an entire week.

Time use of people should not consider each day individually but the entire week as a whole. The way in which time is allocated in an entire week can depend on the time that people want to allocate in the weekend (Astroza et al., 2018). An example of this can be that a recreational activity is planned with friends on the Saturday, so everyone makes sure that their work is finished before Saturday. The research by Astroza et al., 2018 showed some interesting relations such as that females spend more time on shopping and picking people up than males in the entire week, indicating their larger share of tasks in the household. People with a low income spend less time on maintenance and discretionary activities, when compared with people with a high income. This can be explained by their obligation to work longer hours and a lack of resources to participate in these activities. Subsequently, having a household with children means that little time is spend on work in the weekend. Lastly, people who use active modes regularly spend more time on recreational activities in the week and weekend. These findings should of course be generalised but they are an indicator of how different people allocate their time, or how their personal situation impacts this. A decision to pursue an activity is not made on the day itself but there are corresponding relations with other days of the week. Highlighting the significance of using multi-day travel data to analyse travel behaviour of an entire week instead of a single day.

2.5. Joint travel in the weekend

The composition of a household has an impact on joint travel of people and it is interesting to see whether there are large differences between work- and weekend days. Ho and Mulley, 2013 compared how likely it is that people make full or partly shared household tours on work- or weekend days. The research showed that workdays are characterised by partly shared rides between household members and that the weekend has more activities where the entire household shares a ride. An example of this is that on workdays, someone is dropped off at school before the other household member goes to work. On a weekend day, a family might have planned a social activity and they need to pick up someone who arrives by train from a different city, before they can go to the social activity. Household structures thus determine how trips are chained but the different constraints that people have in the weekend also make sure that there are more possibilities for joint travel.

Next to the household structure, there are other factors that influence joint travel. Firstly, the age of people in the household can influence this a lot. For example, the number of children in a household determines whether they need to be driven to school or if they can cycle themselves (Srinivasan & Bhat, 2006). Next to this, the presence of children also has an effect on the time spend on non-work activities in weekends (Astroza et al., 2018). At a later age, joint travel arrangements might shift to travelling with friends but the available modes of transport also influence this. Students rely a lot on public transport or bicycles as a mode of transport while in some cases they can borrow the family car. If a car is available to use, differs per household and it depends on the activity pattern of household members but the weekend is generally more flexible in terms of car availability. In addition to this, Raux et al., 2016 found that higher car availability leads to more time spent on joint travel and activities. To conclude, these are all different factors which influence joint household travel but the most important factors which determine whether joint household travel occurs, is the age of the individual(s), trip purpose and the composition of the household (Ho & Mulley, 2013).

2.6. External effects on weekend travel

There are different aspects that influence a person to make a trip, this can be guided by the need to perform a certain activity or by external factors such as the weather. The weekend is different in the activities that are chosen but what are external and seasonal factors that differ between work- and weekend days? C. Liu et al., 2015 showed that changes in weather have a larger impact on commuters than on non-commuters. Especially heavy rain and reduced visibility discourage people to perform non-work activities. People going to school or work will have to travel, regardless of the weather, while people without these obligations can choose to perform an activity at a different time or day.

It would be interesting to know whether other external factors have a similar influence on the choice to travel as the weather has. Especially because the weekend has less time constraints, people might show a similar tendency to perform an activity at a different time, based on weather conditions or other external factors. To the best of the author's knowledge, not many external or seasonal factors have been studied specifically for the weekend or the effect of these factors was small (Sall & Bhat, 2007).

Therefore, it is still a hypothesis that the following factors have a direct effect on the choice to travel in the weekend. For example, more maintenance is performed on roads and train tracks in the weekend as this has less impact on regular work travel and it's generally less busy. In some cases, this can lead to large disruptions on the transport network, up to the point where the problem spills to alternative routes. A similar situation can occur in the case of a large event. Many people might take the same train or they are on the road at the same time. These situations can have an impact on the choice to travel but this can differ per activity. Do people for example consider the impact of maintenance activities on their route when planning an activity or is this not considered at all?

These were examples of reasons not to travel but there can also be external factors which influence the choice to travel in a positive way. Sales in clothing shops occur yearly at the end of winter and summer. This can attract extra visitors than when there is no sale. Just like this example, there can be many different seasonal habits in the activities that are performed by people which increase the likeliness that a certain activity is performed. The question remains whether the impact of external and seasonal factors is larger on weekend days than on workdays and how often this factor has an impact. If so, there would be more reason to conclude that these factors have an impact on an average weekend day.

2.7. Conclusion

This chapter sets out to answer sub-question 1: *What are travel patterns and characteristics of travel on a Saturday in comparison with a regular weekday and Sunday?*. This was done with an exploratory literature review into differences in travel patterns and this resulted into a number of key findings on differences between work- and weekend travel, which can be seen in table 2.3. Some of the key findings provide very distinct differences in travel behaviour, such as the difference in trip purposes between work- and weekend days, while others describe complex concepts in travel behaviour, such as trip-chaining behaviour, which consists of multiple choices that people make.

Table 2.3: Differences between work and weekend day travel, from literature

	Characteristics		
C1	Different trip purposes have a higher share in the weekend.	C7	Larger difference in trip-chaining behaviour between people.
C2	Saturdays and Sundays show different travel behaviour	C8	The choice for an activity is more important than the choice for a mode of transport.
C3	There is more difference in activity patterns between persons	C9	There is more joint travel in the weekend, especially within a household
C4	The weekend has different constraints/obligations. Therefore, a higher temporal variability of travel.	C10	Mode choice is different
C5	Spatial variability of travel is higher. People tend to explore new activities/destinations	C11	Time of day of travel is different
C6	The value of travel time is different	C12	External effects might have a larger effect on weekend days than on workdays.

The main conclusion from this chapter is that travel behaviour in the weekend is fundamentally different from workday travel due to the different temporal constraints that people experience in the weekend. Constraints from work or school determine a large part of workday travel behaviour and as these constraints are different in the weekend, people plan different activities. As a result, there is more variation between people in the type and number of activities that are performed than on workdays. Furthermore, weekend days are characterised by socio-recreational trip purposes where the Saturday is more oriented on shopping and the Sunday has more social-recreational activities. Finally, time use of a person in the week is dependent on time use in the weekend. Omitting that this dependency exists results in a poor understanding of the activity pattern of a person, especially because consequent weekend days vary more per person than workdays.

The characteristics shown in table 2.3 will be used in chapter 3 to determine how these findings can be translated to adaptations in a transport model. Table 2.4 further shows two recommendations which are not necessarily differences between work and weekend days but aspects that are important to consider about weekend travel behaviour.

Table 2.4: Aspects to consider for weekend travel behaviour

	Recommendations
R1	Recreational time use is subject to change over longer periods of time. Important to consider future recreational time use.
R2	Time use during the week has an effect on time use in the weekend. Important to consider the complete activity pattern of a person

3
Reviewing modelling adaptations for weekend travel

A vast variety of models and modelling approaches exist to model travel patterns. As weekend transport models are relatively unknown, it is necessary to investigate how existing modelling approaches can be used to adapt an existing transport workday model into a Saturday model. This is done by firstly exploring what type of weekend models exist. How do they work and what approaches were used? Secondly, an overview is given of how a trip-based four step transport model works. The components of the model and the underlying assumptions to model travel behaviour are presented. This is crucial information to understand what type of model adaptations can be made to a workday model. Thirdly, modelling approaches for non-work trip purposes are reviewed to not only limit the reviewed papers to weekend models. Non-work trip purposes are a core part of weekend travel so knowledge of existing modelling approaches can help to find modelling adaptations. The collected information from these three parts of the literature can then be used to find and substantiate modelling adaptations for the main differences in work and weekend travel from chapter 2. It is discussed how these differences can be adapted into model adaptations and what is required to do so. This is all done to answer sub-question 2:

2. What are existing modelling approaches for weekend models or non-work trip purposes and can these be used to adapt the BBMA model?

In short, the findings in this chapter will be used to determine the current state of weekend transport models and of non-work modelling approaches that can be used to adapt the BBMA model. The adaptations will be ranked on the effort that is required to implement them in a workday model and on the benefit that the adaptation brings in it's ability to model Saturday travel behaviour. This information will be used in chapter 6 to determine what model adaptations can be done to the BBMA model and which should be prioritized.

This chapter is structured in the following way, first the review methodology is discussed in 3.1. Secondly, the current state of weekend transport models is presented in section 3.2 and an overview of the four-step transport model is given in section 3.3. Section 3.4 then further discusses modelling approaches for non-work trip purposes. Section 3.5 analyses what model adaptations suit the differences between work- and weekend travel that were found in Chapter 2. Lastly, the conclusion of this chapter is shown in section 3.6.

3.1. Review methodology

A similar review methodology was used as the previous chapter in section 2.1. The keywords that are used differ and different selection criteria were used to explore the vast collection of modelling approaches in the literature. An overview of the keywords that were used is shown in table 3.1.

In the search for papers, a keyword from both categories was used. This resulted in a selection of

Table 3.1: Used search keywords for literature into modelling approaches

Category	Keyword
Model keywords	”Trip generation”, ”Trip attraction”, ”Trip production”, ”Trip purpose”, ”Trip generation rate”, ”Transport demand model”, ”Land use”, ”OD-matrix estimation”, ”person-category model”, ”transport model”, ”Gravity model”, ”Trip distribution”, ”Destination choice”, ”four-step model”
Weekend travel keywords	”weekend”, ”workday”, ”Saturday”, ”Sunday”, ”leisure travel”, ”non-work”, ”discretionary travel”, ”maintenance travel”, ”day-to-day variability”, ”shopping”

45 papers from which 20 papers were used in this chapter. A large number of papers was found that described non-work modelling approaches but they were excluded as the papers didn't have a sufficient level of detail, or the paper presented a general modelling approach to improve a certain component of a transport model. Although these are interesting sources and they can be used to present the state-of-the-art in modelling, they are not applicable to non-work modelling approaches.

Next to these search criteria, the scope of this research limits the number of papers that were used. As was stated in the scope, the review into modelling approaches will be limited to modelling approaches that fall within the modelling framework of the BBMA model. This doesn't mean that relevant modelling approaches should fit directly into the current structure of the BBMA model but that they should fit into the rationale of the model. For example, the BBMA model is trip-based, so a tour-based approach doesn't fit in the scope of the BBMA model. Still, interesting modelling approaches can be taken from these kind of papers if they were found to be applicable.

Lastly, it should be mentioned that it was not the goal of this research to present an all-encompassing overview of all the existing modelling approaches and modelling paradigms. It is therefore possible that some papers were missed which present a relevant modelling approaches. Secondly, this research will thus not develop a Saturday model conceptually by comparing the existing modelling paradigms.

3.2. Weekend transport models

This section will present the current state of weekend transport models that were found in this research. This is done to investigate how a weekend model should be developed and what lessons can be learned from previously developed models. Weekend models that were found in the literature are thus analysed in detail. It should be mentioned that the reviewed literature in this section was limited to trip-based models due to the scope of this research.

Weekend transport models that are found in literature have been setup as an experiment by researchers to investigate how a weekend transport model might work. Oliver and van Vuren, 2010 made an effort to model weekend travel by applying a factor to inter-peak workday travel demand matrices. Based on national travel data in the UK, factors were created to convert the workday matrices to a Saturday and a Sunday. It was found that a factor approach per trip purpose delivered the best results but the approach can not capture travel to weekend-related destinations effectively. The factor approach is thereby limited in it's portrayal of weekend travel, as the model can only quantify traffic flows for a weekend day and the approach lacks a behavioural basis of weekend travel.

A mode choice model for the weekend was developed by R. Liu et al., 2010 for the New Jersey area. Initially, the plan was to create a statewide weekend transport model but there was no data source which could suite this type of model. It was then decided that a pilot model would be created on a corridor, together with additional data collection on the use of public transport, as only data on car use was available. The developed model only uses two trip purposes to describe weekend travel, which is work-related or recreational. The variables in the model were based on a previous workday model, while the calibration was done with weekend travel data, as there was too little data to estimate the variables. The model showed sensible results for mode choice in the weekend but the results are confined to the chosen corridor in the model. Next to this, the number of trip purposes in the model limits the analysis that can be done with the model and this example shows the importance of available data to develop a weekend model. Lastly, a mode choice model can only be used to predict a part of travel behaviour and a more extensive model is required to predict further aspects of travel behaviour.

In another study, weekday and weekend trip generation models were compared (Qawasmeh et al., n.d.). A simple regression model was estimated to determine which variables influence trip generation. It was found that the education level of an individual and the number of non-workers are crucial variables for weekday travel. For weekend travel, this was the existence of children and household income. The regression model was not made per trip purpose so the results of this study are about general travel behaviour. If more trip purposes were used, a variable like the number of non-workers would not influence the number of work trips but the number of shopping trips for example. For weekend travel, the results of this study can give an idea for variables that can be used in a trip generation model.

Considering, the weekend models that were discussed in this section, it is evident that little is done to model weekend travel in a detailed way for trip-based models. The reviewed literature doesn't show where development of a trip-based transport model should begin or if such a model requires fundamental changes from an existing workday model. Despite this, a few lessons can be taken from this section. Firstly, a number of trip purposes is required to adequately model travel behaviour. Secondly, the available data is determinative for the level of detail that can be acquired with the model. Lastly, the development of a weekend model does not seem to be hindered conceptually but by data requirements, effort and whether the use-case of such a model can be justified by the required investment.

3.3. The four-step transport model

The four-step transport model is a modelling framework in which the BBMA model that is used in this research falls. This section gives a general overview of the four-step transport model and it lists properties and limitations of the four-step transport model which impose important decisions for a modeller. These properties and limitations can be used later to make informed decisions about the required adaptations for a Saturday transport model.

The conventional approach to model transport systems is the four-step transport model. The goal of these models is to quantify the transport demand and to analyse changes in the transport system (van Nes & de Jong, 2020). The overall structure of the four-step approach can be seen in figure 3.1, but first the topological unit of a transport model is discussed. These are zones, the study area is divided into a number of zones. All trips in the model begin or end in a zone and the model has detailed data on the number of households or other variables per zone. The transport network in the model is build with links and nodes for the modalities that are present in the model, which thus connects the zones to simulate travel. Usually, Car traffic, public transport and cycling are present in the model.

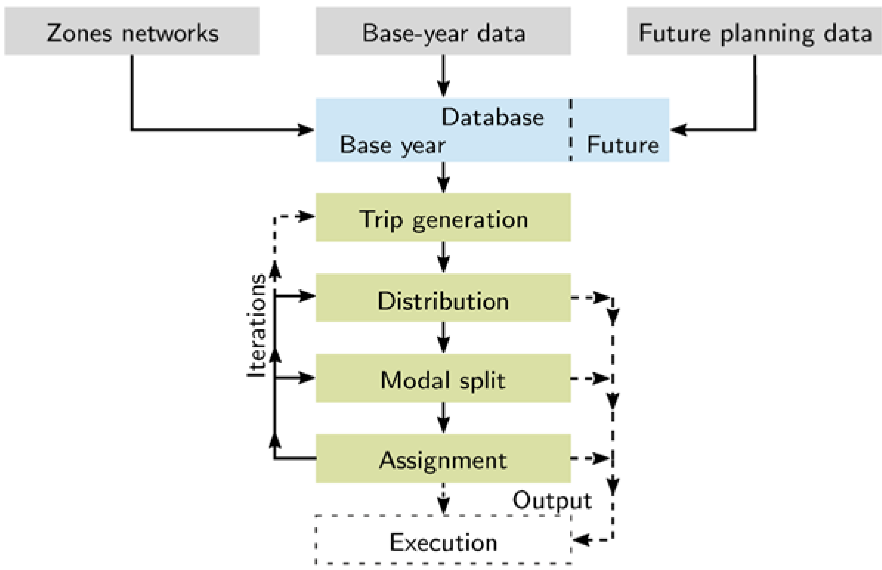


Figure 3.1: Structure of four-step transport models, (Ortúzar & Willumsen, 2011)

The model has four components or sub models. In trip generation, the number of trips originating and arriving in a zone is calculated. Trip distribution or destination then calculates to which zones the traffic goes from each zone. This delivers an origin-destination (OD) matrix of all the flows in the network. The modal split calculation then splits these trips up over the modes in the model. In the assignment step, the flow on the transport network is calculated based on the OD matrix per mode. Resulting in flows on links and nodes.

These steps are performed for different trip purposes as differentiating between trip purposes gives more detailed model results. This is because each trip purpose has different characteristics in the form of different destinations, which in turn influence the decision for a mode of transport. For workday models, trip purposes like work, education, business or shopping are commonly used. The rest of the trips then fall under the category 'other trips' (van Nes & de Jong, 2020). Despite this importance to use a variety of trip purposes, the literature doesn't asses this important choice in model development. It is probably assumed that the trip purposes are chosen for the type of model that is made. As the use of trip purposes can depend on the amount and type of data that is available.

Observations on trip generation
A trip generation model calculates the number of trips leaving or arriving in a zone. This is also known as trip production or attraction. Different methods exist to calculate trip generation, for example by using households or person-categories as the basis of the model. In general, trip generation models are better at predicting the trip production than trip attraction (Ortúzar & Willumsen, 2011). This is because trip production is determined at the household level with variables such as income, car ownership, household size or population density. It has been shown in practice that a variable such as household size is a good predictor of the number of trips that are made per household and the combination with other variables gives accurate results. For trip attraction, this is done with variables such as the number of available jobs in an area, the number of shops or the size of shops. These variables offer less detail than the trip production variables and they don't offer a clear distinction in why a larger shop size should attract more visitors. The trip attraction is thus something that can be improved in a four-step model and it's also important to consider that the level of detail of a trip attraction variable can greatly influence the results of a model.

As was discussed earlier, differing between trip purpose is a way to create classifications in a four-step model. A classification enables a modeller to show differences in travel behaviour between for example income groups, on top of a classification like trip purpose. Combining different classifications can quickly lead to a large number of groups for the model. For example, a model with 5 trip purposes and 3 income groups has 15 groups in total. This is done in a situation where including the income groups provides additional information on the trip generation behaviour. The data that is then used to create the model, has to be split over the groups. This is where a limitation arises for the model, as not all groups have the same amount of data. Not all groups will produce statistically significant results. A modeller thus has to choose between the level of detail of the model and the data that is available to make the model (Ortúzar & Willumsen, 2011).

Conclusion
This section concludes by listing properties and limitations of the four-step model which were found in literature in this section. These properties and limitations delineate that a modeller has to find a trade-off between the explanatory power of a model by including personal, behavioural or zonal characteristics, like income, trip purpose or urban density, and the available data to make these classifications. An overview of these can be seen in table 3.2

3.4. Modelling approaches in non-work travel motives

As little is known about existing modelling approaches for weekend models, this section will explore what modelling approaches exist for non-work travel motives in workday transport models. In addition to this, the previous section has identified that there is no consensus on which trip purposes should be used in a model and that trip-based transport models are not good at predicting trip attraction. Therefore, these aspects will also be included in this section to identify if relevant modelling approaches exist.

By no means will this section provide a comprehensive overview of all these aspects. During the literature search, a limited number of papers was identified that discuss relevant modelling approaches.

Table 3.2: Properties and limitations of a four-step transport model

	Properties and limitations
F1	Use a select set of trip purposes to model travel behaviour
F2	Four-step models are better at predicting trip generation than trip attraction.
F3	The four-step model is limited in differentiating in personal or zonal characteristics as the required data increases with the number of characteristics that is included.
F4	Fundamental developments in trip-generation models are limited in the literature.

Next to that, the literature search has focused on trip generation or trip attraction models in the search for modelling approaches. It's possible that relevant approaches exist in the literature which fall under a different modelling paradigm, model steps or terminology. A solution for a problem in one modelling paradigm might not exist due to certain limitations, while this problem can be solved easily in a different modelling paradigm.

Non-work trip purposes
An analysis of trip-generation for non-work trip purposes was done by Kim et al., 2021. The author states that non-work trips are highly variable, making it difficult to predict these accurately. In this research, a trip generation was estimated on three types of data, ranging from aggregate to disaggregate. These were zonal-based, household-data and person-based data. A flaw of aggregate models is that they can deliver good statistical results but the underlying theoretical assumption neglects variations between persons as an aggregate model is only estimated on aggregate variables. Therefore, it's logical that a disaggregate model can better explain differences in trip-making behaviour as more detailed data is used. In the results of the study, the person-based model delivered the best statistical fit, while using more explanatory variables than the zonal and household-level model. Variables that were used in the person-based model were: income, number of cars, number of children and the occupation of a person. Although this is an interesting result, the study did not vary in trip purposes and it is not clear from the study whether the used data was from a work- or weekend day. It would be interesting to know how a person-based model would perform for different trip purposes and which variables are relevant per trip purpose. Next to this, the study does not describe how a trip generation model should handle the irregular generation of non-work trips.

A different modelling approach for non-work trip purposes was applied in the Swiss national model (Vrtic et al., 2007). The model is person-based and it employs a non-linear utility function, which ensures that the model is flexible to model different groups, trip purposes or modes of transport. Next to this, the model employs hard and soft constraints for the production and attraction between zones. Normally, a model is constrained at the number of trips that are produced and attracted to a zone. In the trip distribution phase, the model then needs to find a solution where the production/attraction matches the calculated values for all the zones. In this study a different methodology is defined where a hard constraint is for example defined for work trips. It is expected that the number of work trips that arrive to a zone is constant and the number of work trips should thus also match the available workplaces. A soft constraint is imposed on trip purposes such as shopping or leisure. For these kinds of zones The constraint should then be seen as the maximum number of trips that can be attracted to a zone instead of a set number. This allows the model to simulate the competition between zones. This methodology is applied in a destination choice model so it's not known whether this approach is also applicable to a gravity model. If so, the use of soft constraints can be a way to replicate the spatial variability of weekend travel.

Improvement in trip attraction
As was indicated in the previous section, it is difficult for a model to predict the attraction-side of trip generation. In Vrtic et al., 2007, the model uses two attraction variables for shopping trips, which is reflected in a trip rate to normal stores and to shopping centres. For leisure trips, this was done with a variable for leisure facilities. This is a basic way to utilise either the surface area of shops or

the number of employee's for a shop to calculate the number of trips that are attracted to a zone. The underlying assumption of this method is that a zone with a larger surface area of shops, will attract more shopping trips. The method in (Vrtic et al., 2007) only differentiates between two variables to express shopping but (Gonzalez-Feliu et al., 2010) tried to use more variables to do this. A differentiation was made in store size between small and medium stores, supermarkets and big commercial surfaces and lastly hypermarkets or similar stores. This was then done for the number of stores and the number of employees, resulting in 6 variables. Additionally, a binary variable was used to indicate the presence of a commercial centre and a number of socio-demographic variables were included in the modelling process. In the final model, the model only differentiates between two store sizes next to the socio-demographic variables. Apparently, the influence of store size is small on the trip-making behaviour for shopping trips and there is no difference between big stores and hypermarkets.

This statement is backed up by different research, where an accessibility variable was included to predict the number of shopping trips (Kroeger et al., 2018). The idea of an accessibility variable is that the proximity of a store to the household has an impact on the choice to go there. This assumption doesn't hold for work trips as work is carried out at a fixed location, but it's easier to go shopping nearby. The results of the model show that the spatial effects have a low effect on trip-making when compared to socio-demographic variables. Perhaps, the modelling effort should thus not lie in finding more variables which can explain trip attraction, but in using one or two variables with a high level of detail on shopping destinations or by differentiating in the type of shopping trip.

Use of OSM data

Briem et al., 2019 set out to explore the usability of OpenStreetMap (OSM) data for transport models. The author states that the quality of data from public authorities is sometimes not sufficient to model individual destinations. OSM data is publicly available, removing some institutional barriers but increasing the risk of poor data as the quality of the data is not controlled. This is because OSM is maintained by volunteers which add data themselves. The research concluded that OSM data is of sufficient quality, when compared to official data, for educational trips but not for work trips. For work trips, data was still missing or not accurate enough. If this is improved in the coming years, OSM can be a good data source for transport models, given that the data is thoroughly checked on it's plausibility.

In another study, OSM data was used to predict the attractiveness of individual destinations in an agent-based model (Klinkhardt et al., 2021). The study defined 12 trip purposes such as work, business, daily shopping or long-term shopping. Per trip purpose, a list of building types was made from the available OSM data to distinguish relevant building types. For daily shopping, these are then supermarkets or bakery's and for long-term shopping these are clothing or furniture stores. The author then states that not only the correct building type is relevant, but also the degree of attractiveness per building type. This can be calculated by the surface area of a shop, or other variables. It is important to make this distinction as a furniture shop attracts a different number of visitors per square meter, than a book store. Databases which contain trip attraction rates exist for example in the UK (TRICS, 2012), or the USA (Hooper, 2017).

The methodology in the study was then validated on two different ABM's. The acquired data from OSM was compared to official data and once the OSM data has undergone some corrections, the OSM data can predict the surface area with a higher precision. The results of the model were then compared to the existing model and count data of visitors. This showed that the ABM can better capture the relative differences between specific building types than the previous model. Still, the results are not fully comparable to visitor data, as there are more contextual factors which influence the attractiveness of a location. This conclusion also undermines the assumed linear relation between surface area and visitors. Despite this, an attractiveness measure gives a good basis to analyse trip attraction and to later include more contextual factors.

It would be interesting to know if the method proposed by Klinkhardt et al., 2021, is transferable to a zonal-based model. Aggregating variables to a zonal level means that the variation between households or persons is reduced in the aggregated variable. As an example, if two supermarkets exist in one zone, the calculated trip attraction for both supermarkets is combined in the zonal total. The effect of both supermarkets is still there, but the underlying variation between the supermarkets is lost. The question then is, if a higher level of detail in the original variable, improves the aggregated variable when compared with a less detailed variable.

Conclusion
To conclude this section, a variety of lessons can be learned from existing modelling approaches. First of all, little modelling approaches tackle the variable nature of weekend travel. This can be caused by an inability of the model to portray this effect, or because non-work trip purposes are not explicitly modelled. In a study where they were modelled. A person-based model can show the most differences in travel behaviour. Additionally, an aggregate approach poses a limited view of the actual trip-making behaviour over person-based models.

Secondly, it was found that trip attraction models can only be improved marginally with geographic variables. Trip-making behaviour can better be explained with socio-demographic variables at the trip generation side. This is because trip attraction variables are not as detailed as socio-demographic variables. It could thus be that trip attraction can be improved by using variables with a higher level of detail.

3.5. Assessment of modelling adaptations

The reviewed literature on transport models doesn't provide a clear starting point for the development of a weekend model. The previous sections show that a weekend model has not been developed conceptually but that it should be possible to start development from an existing model. The goal of this research was not to develop such a model conceptually but to try and map what modelling approaches can be used to create such a model. To do that, information is required on how a weekend model should differ from a weekday model. In chapter 2, a set of differences was identified between work- and weekend day travel. This section will asses what modelling approaches can be used to model these differences in travel behaviour. This will result in a set of adaptations that are required to make a weekend model. The underlying theory to asses this will come from section 3.3, 3.4 and additional literature.

The way in which this is done is that each characteristic from table 2.3 is discussed separately on how the characteristic can be turned into a model adaptation. This is summarised in a single sentence but the running text also discusses additional requirements for the adaptation such as a certain data analysis or in what part of the model the adaptation needs to be made. Additionally, two recommendations on weekend travel from table 2.4 are also discussed. Lastly, the set of adaptations is classified corresponding to the type of adaptation. An adaptation can be a change to a model property or a model parameter and the impact of these adaptations is not the same.

C1 *Different trip purposes have a higher share in the weekend.*
A weekend model would requires the use of different trip purposes to reflect the different travel behaviour in the weekend. The literature doesn't present a specific set of trip purposes for the weekend and it's possible that this set can also differ between Saturday and Sunday. The data that is used to create the model would have to be analysed to come to a set of trip purposes for a weekend day. Next to that, it should be investigated how the trip purposes can be modelled. This involves the trip generation step of the four-step model but also purpose-specific attributes.

$\rightarrow$ Use different trip purposes in a weekend day model.

C2 *Saturdays and Sundays show different travel behaviour.*
Saturdays and Sundays can be modelled separately. There has to be enough data to do so and the development of such a model has to be justified. If possible, certain model attributes can be used for both weekend days if the difference in the attribute is small.

$\rightarrow$ Model Saturday and Sunday separately.

C3 *There is more difference in activity patterns between persons.*
Activity patterns are used in Activity based models but not in a four-step model. The greater difference between persons can be introduced in a four-step model by incorporating variables or different classifications that reflect these differences in activity patterns. Note that this is not an approximation of the difference in activity patterns but a way to show differences between persons in trip making, destination choice, mode choice or route choice. This can only be done on the level of aggregation of the model itself and it's limited by the data. A data-analysis can show which variables are suited to do this.

→ Incorporate different variables or classifications to show differences in travel behaviour in the model.

C4 *The weekend has different constraints/obligations and therefore a higher temporal variability.*
In general, a four-step model models three time periods which are the morning peak, off-peak and the evening peak. For the model, there is no difference between a shopping trip at 11:00 or 14:00. They both fall in the off-peak. Based on the data, different time periods can be introduced for the model. Additionally, the temporal variability could be introduced in the results of the model by assigning a bandwidth that reflects the uncertainty of the results or a set of scenarios can be simulated from the results by varying the outcome per trip purpose.

→ Model different time periods or show the possible bandwidth of the results.

Including temporal constraints itself is only possible when the activity pattern of a person is regarded. If a model needs to do this, this can be done with an ABM.

C5 *Spatial variability of travel is higher. People tend to explore new activities/destinations.*
Just as temporal variability, spatial variability is a characteristic of travel that is connected to the choices that people make. A four-step model doesn't include this choice itself but it distributes the trips per purpose over a set of destinations to assure this spatial variability. The destinations that thus belong to a specific trip purpose should be included in the model at a zonal level, otherwise the model lacks the level of detail for that trip purpose. This can be done in the trip generation step of the model or in the trip distribution step.

→ Incorporate the possible destinations per trip purpose in the trip generation or trip distribution step of the model.

C6 *Larger difference in trip-chaining behaviour between people*
A trip-based model is not able to include trip-chaining behaviour. This would have to be done with a tour-based model. A trip-based model, models all trip-pair combinations separately like 'Home-Work' or 'Work-Home' but the model assures a certain symmetry for each trip purpose. The assumption of trip-based models between two zones is that the number of work trips going to a zone, is almost equal to the number of work trips returning from that zone. A trip-pair combination like 'Work-Shopping' can be a part of a trip-chain but the model can't link this combination to a preceding 'Home-Work' trip. The model is not able to guarantee the symmetry between work trips if this trip-combination is introduced and the model cant link the 'Work-Shopping' trip to the originating zone of the preceding trip. Another argument to not include all trip-pair combinations in a trip-based model is that this would result in too much combinations. Each combination has to have enough data to estimate it separately and this is not feasible for every combination.

→ Consider a tour-based model, if this is required.

C7 *The choice for an activity is more important than the choice for a mode of transport.*
This characteristic showcases the hierarchy of the decision-making process of people for travel decisions. In general, the four-step model follows a structured hierarchy where trip choice, destination choice, mode choice and route choice are treated as separate choices in the four sub-models. A detailed analysis of how good this structure adheres to the true decision-making process of people is too detailed for this study. Some modelling frameworks are better at replicating the dependency between activity choice and mode choice, while other models regard these as separate(Ortúzar & Willumsen, 2011). It's thus not possible to include this characteristic as a simple model adaptation as it depends on the model how this characteristic is included. Finally, the changes between work- and weekend day travel that were found by Habib, 2011 don't require a different modelling framework, but a different portrayal of the importance of the travel choices.

→ Asses whether the model structure is sufficient to model the dependency between activity choice, destination choice, mode choice and route choice in the model.

C8 *There is more joint travel in the weekend, especially within a household*
Just as with other aspects of the model, the required level of detail indicates how joint travel can

be incorporated in a model. A detailed approach would be to include social-network relations or the household constitution into an activity-based model to model joint travel arrangements. An approach that fits in the four-step model is too include the household size or the presence of children as a variable in the trip generation model. Alternatively, the car occupancy rate can be adjusted per trip purpose to reflect the change in joint travel for a weekend day. This would require a data-analysis to come to an accurate number for the car occupancy rate.

→ Include variables that reflect joint travel or update the attribute in the model.

C9 *Mode choice is different*
The mode choice step of the model should be updated to reflect the change in mode choice in the weekend. Depending on the complexity of the mode choice model, a parameter needs to be re-estimated to reflect the preferences for certain modes. On top of that, variables or attributes can be adjusted to reflect different sensitivities for travel time or joint travel.

→ Re-estimate the mode choice step.

C10 *Time of day of travel is different*
This characteristic is similar to characteristic C4. Modelling the time of day of travel can be done by including different time-periods. If a model needs to showcase the time of travel in a more detailed way. An ABM can be considered which simulates time.

→ Model different time-periods.

C11 *The value of travel time is different*
The value of travel time is a parameter which can be derived from literature (KIM, 2023), or it can be estimated from a data-analysis. The parameter can differ per trip purpose to get the most detailed model results.

→ Re-estimate the VOT and other required attributes for a weekend day model.

C12 *External effects might have a larger effect on weekend days than on workdays.*
External effects like road works, events or seasonal variations can all have a different effect on the choice to travel in the weekend as there are less constraints to travel. Just as for characteristic C4, this can be reflected in the outcome of the model by including a certain bandwidth or scenario's of results. Only now, this should not be done per purpose, but for certain scenario's that reflect the external effects.

→ Consider a certain bandwidth in the models results or a standard set of variants which reflect these external factors.

From these adaptations, the majority can be implemented in a four-step model but some can only be implemented in an activity-based model. Therefore, it has to be checked whether an adaptation can fit in the setup of the model that is adapted. An overview of the characteristics, the corresponding adaptation and the classification can be seen in table 3.4. Next to the differences in work- and weekday travel. Chapter 2 identified two aspects of travel behaviour that could be important in a weekend model, these are described below.

R1 *Recreational time use is subject to change over longer periods of time.*
A transport model can predict future years with a growth model, such a model has sensitivities for a set of aspects that can change in the future. As leisure time use is more prominent in the weekend, a sensitivity analysis of recreational time use should be included in the prediction for future years.

→ The prediction of future years should incorporate the possible change in recreational time use.

R2 *Time use during the week has an effect on time use in the weekend.*
Travel behaviour between days of the week is dependent on each other, therefore it's important to consider the complete activity pattern of a person in a transport model. An aggregate model

can not create this dependency between different days but an activity based model that models an entire week is suitable for this.

→ Use a week-long ABM model to do this.

The identified adaptations C1 to C12 are classified into the effort that is required to model the adaptation and the perceived benefit that the adaptation brings in it's mobility to model Saturday travel behaviour over the other adaptations. In other words, what realism does the adaptation bring to model a Saturday and how much work does this cost. The adaptations are ranked on a scale from low to high, based on expert judgement, the result of this can be seen in table 3.3.

For adaptation C1, a medium effort is required where the bulk of the work lies in figuring out which trip purposes should be in the model, based on the data is used. Implementing the new trip purposes is then a low effort, depending on the flexibility of the software of the model. The perceived benefit of adapting the trip purposes is high and can be seen as a necessary adaptation for a Saturday model. Adaptation C2 is comparable to C1 in the sense that most of the work lies in getting the right data for a Saturday. This should require little work, while the benefit is high or even necessary. Adaptation C3, requires a high amount of effort as choosing the right classifications for a Saturday model can be a process of trial and error in the model itself or in a data-analysis. The flexibility of the software can also play a large part in this adaptation. The perceived benefit is seen as medium as a classification provides more detail on top of the chosen trip purposes. This is therefore not a necessary adaptation.

Depending on the flexibility of the software, adaptation C4 requires a low amount of effort both in implementation and in the data analysis. The perceived benefit of modelling time periods for a Saturday is medium as this is a result which is often used to predict peak traffic. The required effort for adaptation C5 can range from medium to high, depending on the thoroughness in which the adaptation is implemented. This depends on the data source that is chosen to model the destinations per trip purpose. and how extensive this data should be analysed, before it can be used in the model. After that, a process of trial and error is necessary to verify that the model works with the adaptation. Adaptation C6 requires a tour-based model, so this adaptation would require a model that is not trip-based. This research doesn't assume the effort and benefit of this adaptation as it is assumed that this adaptation is made in a tour-based model and not from a trip-based model.

Adaptation C7 requires a high amount of effort as it's possible that the entire structure of the model needs to be reworked to model the dependencies between activity choice, destination choice, mode choice and route choice. The perceived benefit of this adaptation is low, as only the rationale of the model is different but the outcome of the model will be the same. A low effort is required to model adaptation C8 as this only requires a change in the attributes of the model. The benefit in the added functionality is perceived as low, as it is a change in aggregate attribute. Adaptation C9 requires a medium effort to implement, estimating mode choice is a part of making a model and re-estimating the mode choice is then part of this process. The perceived benefit of the adaptation is high, as portraying mode choice correctly is a crucial part of travel behaviour.

Adaptation C10 is similar to adaptation C4 so the required effort and perceived benefit are set at the same rank, which is a low effort and a low benefit. Adaptation C11 is about the change in different attributes which are used in the model. It is likely that new values for these attributes will have to be collected via data-analysis as these are not known yet for weekend-related trip purposes so the required effort is set on medium. For an attribute like the VoT, the effort would be high as this requires a separate research. The benefit of these changes in attributes is low as it is likely that the values will not differ largely from existing values used for a trip purpose like "Other". The last adaptation describes the influence of external effects. Implementing this is seen as a medium effort but it's also not yet clear what this adaptation really contains. This adaptation can also be part of a specific use case for a model. The perceived benefit is therefore low, as it's not a direct influence on Saturday travel.

To conclude this section, a set of adaptations is presented which show how differences in work- and weekend day travel can be adapted into a weekend model. From the set of adaptations it can be concluded that a weekend model doesn't necessarily require a new modelling paradigm but that a first effort can be made in changing model properties, model components, input data and model parameters. From the adaptations, C1 and C2 are seen as necessary adaptations to make a Saturday model.

Table 3.3: Overview of the required effort and perceived benefit per characteristic based on expert judgement

Characteristics		Effort	Benefit
C1*	Different trip purposes have a higher share in the weekend	Medium	High
C2*	Saturdays and Sundays show different travel behaviour	Low	High
C3	There is more difference in activity patterns between persons	High	Medium
C4	The weekend has different constraints/obligations and therefore a higher temporal variability	Low	Low
C5	Spatial variability of travel is higher	Medium	High
C6	Larger difference in trip-chaining between people	-	-
C7	The choice for an activity is more important than the choice for a mode of transport	High	Low
C8	There is more joint travel in the weekend	Low	Low
C9	Mode choice is different	Medium	High
C10	Time of day of travel is different	Low	Low
C11	The value of travel time is different	Medium	Low
C12	External effects can have an effect on weekend travel	Medium	Low

**necessary adaptation for a Saturday model*

A recurring theme for each adaptation was that a trip-based based model has it's limitations in how detailed the characteristic can be incorporated in the model. This should be taken in regard if a transport model is created that is not bound to the four-step model framework.

3.6. Conclusion

The literature review in this chapter answers sub-question 2 *What are existing modelling approaches for weekend models and non-work trip purposes and can these be used to adapt the BBMA model?* First of all, section 3.2 showed that there is no clear modelling approach for weekend models and that development on them has been limited but also that the development of such a model is not limited conceptually to a certain modelling paradigm but by data requirements. Section 3.4 then further contributes to the reviewed literature with modelling approaches for non-work trip purposes. Although little effort has been made to model non-work trip purposes, some interesting modelling approaches can be taken from this section. The real answer to the sub-question comes in section 3.5 by showing how differences in work - and weekend travel can be used to come up with modelling adaptations for a Saturday model. The modelling adaptations are ranked on the required effort to implement the adaptation and the perceived benefit of the adaptation in it's ability to model Saturday travel behaviour. Two modelling adaptations were found too be necessary to construct a Saturday model, which is too change the trip purposes in the model and too use Saturday related travel data. Additionally, from the proposed modelling adaptations, some adaptations are not suitable to implement in a four-step model but it can be that these adaptations fit in an activity-based model.

Lastly, section 3.3 has given an overview of the four-step model and it gives a set of properties and limitations of the four-step model which a modeller should pay attention to. Lastly, table 3.4 shows the set of adaptations that were found from differences in work- or weekend travel.

Table 3.4: Overview of characteristic differences in work- an weekend day travel, with the corresponding adaptation and effort/benefit

	Characteristics	Adaptation	Effort - Benefit
C1*	Different trip purposes have a higher share in the weekend.	Use different trip purposes in a weekend day model	Medium - High
C2*	Saturdays and Sundays show different travel behaviour	Model Saturday and Sunday separately	Low - High
C3	There is more difference in activity patterns between persons.	Incorporate different variables or classifications to show differences in travel behaviour in the model	High - Medium
C4	The weekend has different constraints/obligations and therefore a higher temporal variability.	Model different time periods or show the possible bandwidth of the results	Low - Low
C5	Spatial variability of travel is higher, people tend to explore new activities/destinations.	Incorporate the possible destinations per trip purpose in the trip generation or trip distribution step of the model.	Medium - High
C6	Larger difference in trip-chaining behaviour between people	Consider a tour-based model, if this is required.	-
C7	The choice for an activity is more important than the choice for a mode of transport.	Asses whether the model structure is sufficient to model the dependency between activity choice, destination choice, mode choice and route choice in the model.	High - Low
C8	There is more joint travel in the weekend, especially within a household	Include variables that reflect joint travel or update the attribute in the model.	Low - Low
C9	Mode choice is different	Re-estimate mode choice parameters	Medium - High
C10	Time of day of travel is different	Model different time-periods.	Low - Low
C11	The value of travel time is different	Re-estimate the VOT and other required attributes for a weekend day model.	Medium - Low
C12	External effects like road works, events or seasonal variations can all have a different effect on the choice to travel in the weekend as there are less constraints to travel.	Consider a certain bandwidth in the models results or a standard set of variants which reflect these external factors.	Medium - Low

**necessary adaptation for a Saturday model*

4

ODiN data analysis of weekend travel

Travel behaviour can be made insightful by uncovering patterns in travel data of people. A sub-goal of this research is to uncover these differences between work- and weekend day travel, to get a clear overview of travel behaviour on weekend days. This is done to partly answer sub-question 1 by analysing the ODiN dataset from multiple years (CBS, 2024b):

1. What are travel patterns and characteristics of travel on a Saturday in comparison with a regular workday and Sunday?

The data-analysis will focus on investigating differences between work - and weekend days, but also on differences between workdays, to uncover if there is indeed a difference between work- and weekend days, or if the days should be regarded separately. The data-analysis will focus on aggregate statistics such as trip purpose, modal split, trip length distribution and possible differences in trip-chaining. An additional reason to focus on these aggregate statistics, is because differences in travel behaviour between trip purposes, allow a modeller to identify classifications in the data which can be used later to make classifications in a transport model. Next to this, Chapter 3 has identified that there is no clear trip purpose distribution that should be used for a Saturday model, therefore this chapter describes how a Saturday trip purpose distribution can be made, based on the ODiN data.

The data-analysis will focus on investigating differences between corresponding days, differences in trip purposes, modal split, trip length distribution, time of day, type of trips per trip purpose, trip-chaining/tours. For this analysis, it is important to consider that differences between workdays and the weekend do not necessarily stem from a difference between workdays and the weekend but they can also be caused by day-to-day variation of travel behaviour, or by trip purpose.

The structure of this chapter is the following: First, the ODiN dataset is described and the survey approach behind the dataset in section 4.1. In section 4.2, descriptive statistics are presented on differences between work - and weekend day travel from the ODiN data. Thirdly, section 4.3 shows how a Saturday trip purpose distribution can be constructed from ODiN data, and section 4.4 concludes the chapter.

4.1. ODiN data description

As the main data source, the ODiN (Onderweg in Nederland) survey will be used (CBS, 2024b). This is an annual household survey with around 50.000 to 60.000 respondents per year. Each respondent has to report the trips that they made on a specific day and extra questions are asked about the personal situation of the respondent and their ability to travel. The survey is carried out by CBS (Centraal Bureau voor de Statistiek), which is a Dutch government organisation that gathers statistics. The goal of the ODiN survey is to get an understanding of nationwide travel behaviour, so that it can be used by the government, research institutes and society. Therefore, the dataset is openly available.

The ODiN survey stands out from regular travel surveys in that it collects data throughout an entire year instead of from a single day. This approach has numerous advantages, as the seasonal variations in travel demand can be captured, without requiring respondents to do a survey for multiple days or weeks (Ortúzar & Willumsen, 2011). A disadvantage of the survey setup is that a complex weighing process is required to account for seasonal variations or under-represented regions in the survey. Next to this, travel surveys which span longer than a week per respondent are better suited to analyse day-to-day variation in travel behaviour, as more information is collected per individual. Despite that, the current survey setup is sufficient to analyse nationwide and regional travel behaviour.

The survey design for ODiN has stayed the same from 2018 onwards. Before 2018, a different survey design was used and therefore the results from the so called OViN surveys is not comparable with ODiN. The CBS does a plausibility check of the data to see if there are any significant changes between survey years, to check whether the consequent years are comparable. Next to this, the data is corrected on unrealistic results and other checks are performed by the CBS to assure the consistency and quality of the data. For more information, the reader is referred to the documentation of ODiN (CBS, 2024b).

First, data from different years was merged to create one dataset. The years that were used were: 2018, 2019, 2022 and 2023. The results from 2020 and 2021 were unusable due to the effects on Covid-19 on travel behaviour. Using these years would give a distorted view of travel behaviour as less trips were made and the travel behaviour is not coherent with the behaviour before and after Covid-19. Realistically speaking, traffic volumes at the start of 2022 were not comparable yet with before Covid-19 but the data is still usable. Due to the extensive data-filtering process of the CBS, this is not done in this research.

Before the data could be used for this research, certain types of trips had to be removed from the dataset as these are not relevant. These are serial movements, movements with freight trucks, or serial movements with freight trucks. Freight travel is not included in the scope of this research, so therefore these are excluded. A serial movement is a trip with multiple stops on the way. These kinds of trips are mostly work-related, for example by a courier who delivers parcels. These kinds of trips are difficult to analyse and this kind of travel behaviour is difficult to include in a transport model. Therefore, serial movements are not included in this research. Lastly, multimodal trips or rides in the dataset are reduced to the main trip. A ride is comparable to a serial movement but a ride has more information in it. The additional information on access/egress modes or small stops is discarded, as this is difficult to include in the analysis.

4.2. Differences between work and weekend travel from ODiN data

This section will describe the data-analysis that is performed with the ODiN dataset, to uncover differences in work- and weekend day travel. The section starts by looking at which trip purposes are present in the ODiN data and it is then shown what the share is of these trip purposes per day. The analysis then continues by looking at differences in the modal split, trip length and trip-chaining behaviour. Lastly, the trip-purpose is analyzed per direction of the trip.

4.2.1. ODiN Trip purposes on workdays and weekend days

Trip purpose is the main indicator for what kind of trip someone made. 14 trip purposes are used in the ODiN survey, listed listed in table 4.1. These trip purposes are an aggregate portrayal of the type of trip that is made, but they can be used to discover differences between the trip purposes.

Table 4.1: Trip purposes defined in ODiN

ODiN Purpose	
1. Going Home	8. Shopping
2. Work	9. Visting family or friends
3. Business-related	10. Touring/walking
4. Occupational	11. Sport/hobby
5. Drop off/ Pick up persons	12. Other recreational activities
6. Drop off/ Pick up goods	13. Services/ Personal business
7. Education	14. Other purpose

Trips that are made in the weekend are characterised by different trip purposes than for trips made on workdays. Figure 4.1 shows the percentage of each trip purpose on workdays, Saturdays or Sundays. As the workdays are based on more days, comparing the total number of trips is not possible. By showing the percentages, it's possible to look at the differences between the different days.

The purpose 'No trips made' shows the percentage of respondents that stayed home at the day in which they filled in the ODiN survey. From this trip purpose, it can be concluded that more people stay at home on weekend days, especially on Sundays. As a result, less people are 'going home' on Sundays. Despite this, 'touring/walking', 'other recreational activities' or 'visiting family or friends' are trip purposes that stand out on Sundays. The trip purposes also have a higher percentage on Saturdays when compared to the workdays and these trip purposes highlight the recreational nature of the weekend. People go for a stroll to the beach, visit family or they perform a recreational activity.

Saturdays are more maintenance oriented with trip purposes like 'shopping', 'sport/hobby' or 'dropping off/picking up goods' which stand out. These tasks seem logical for a Saturday where extra time is available to do activities which didn't fit in the rest of the week. Especially 'shopping' stands out on Saturdays but it should be mentioned that this is an activity which happens regularly on workdays.

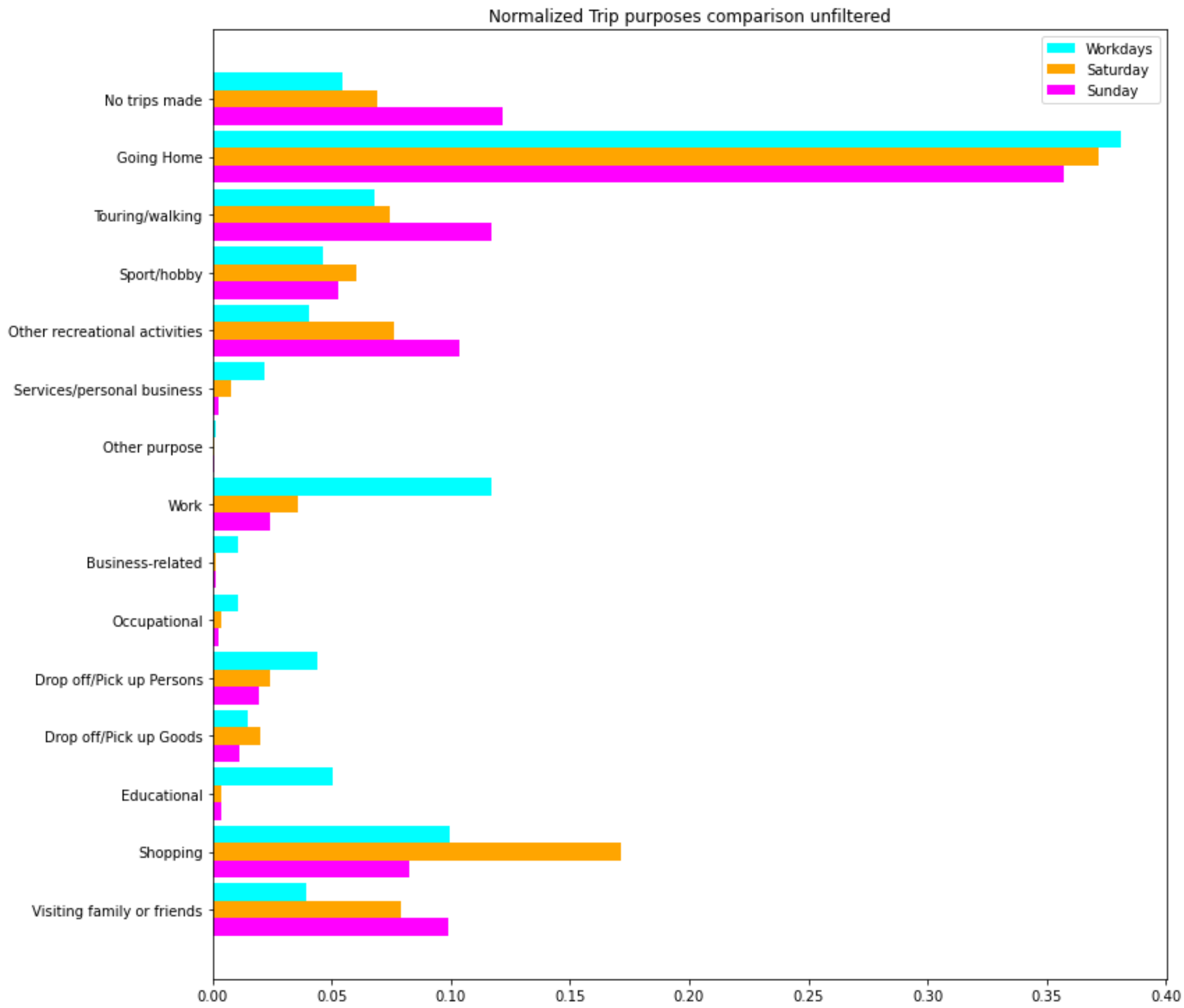


Figure 4.1: Percentage of ODiN trip purpose per workday, Saturday and Sunday

Typical workday activities such as 'Work', 'Business-related', 'Occupational' and 'Educational' have a lower share in the weekend up to the point that some of these trips are rarely made in the weekend. 'Services/personal business' and 'Dropping off/picking up people' also have a lower share in the weekend. These can be trips like going to the dentist or bringing children to school. As both of these type of destinations are closed in the weekend, it is logical that less of these trips are made. For some jobs, such as in a hospital, work has to be done in the weekend so these trips are still made in the weekend. Altogether, workdays, Saturdays and Sundays can thus be characterized by different trip purposes.

4.2.2. ODiN trip purposes per day

From the previous section, it followed that work- and weekend days have a different share of trip purposes. It is possible that this is not purely related to the weekend. Trip purposes can also vary per day as each day is perceived differently or people have a preference to perform certain activities on a specific day. This can be a weekly sport activity on Tuesday or a preference to go grocery shopping on Monday for the rest of the week. Figure 4.2 shows the percentage of trips that were made of six different trip purposes for all weekdays. Not all trip purposes are shown here as some trip purposes show similar patterns between weekdays, a figure with the remaining trip purposes can be seen in Appendix C. Note that the differences shown in the figure are between the trip purposes itself. A 5% difference in shopping trips between Thursday and Friday doesn't mean that there are more trips in total but this is relative to the number of shopping trips.

The trip purpose 'Going Home' roughly shows how the total number of trips made per day differs. This confirms that less trips are made in the weekend while the workdays are rather constant. Furthermore, it can be seen in the figures that for some trip purposes, there is a clear workday-weekend day difference, while for other trip purposes this difference is more nuanced. For example for the trip purpose 'Other Recreational Activities' there are more of these type of trips in the weekend, but the trip purpose Shopping has a low share of these trips on Sunday and the highest share on Friday and Saturday. Interestingly, for some leisure trip purposes, the share of trips ramps up from Monday to the weekend. At the start of the week there is thus a lower need to perform these kinds of activities while this increases for the rest of the week.

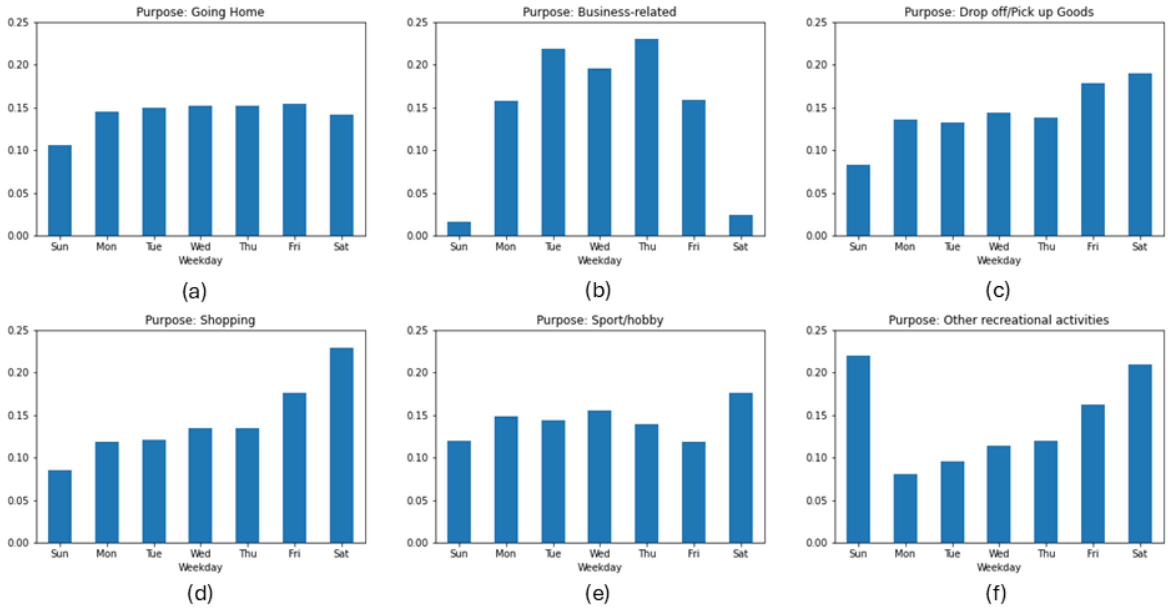


Figure 4.2: Percentages of trips made for different ODiN trip purposes over all weekdays

Furthermore, it can be seen that Friday has a higher share of trips over workdays for some trip purposes. Apart from the work-weekend day difference, the Friday can be seen as a sort of pre-weekend day as it has a higher share in multiple trip purposes. Consequently, it can be seen that there is a Tuesday-Thursday effect, when compared with the other workdays, such as for the trip-purpose 'Business-related'. This leaves the question whether the average workday is a correct distinction to make, or if workday should be regarded separately. To conclude, differences in trip purpose are not bound to a workday-weekend day distinction but trip purposes vary per day and over the course of the week.

4.2.3. Modal split in ODiN

The modal split for weekend days is different than for the average workday. As can be seen in figure 4.3, the share of car passengers is much higher on both weekend days. This can be explained by the fact that more people travel together in the weekend and the availability of the car in the household might be higher. If normally, the car is used to drive to work by a single person. The rest of the household has to rely on other modes of transport. Next to that, public transport and bicycle use is relatively lower. This directly relates back to the better car availability in the weekend, as people don't have to cycle to school but they can take the car. This doesn't mean that all bicycle users turn into car passengers in the weekend. It's still possible that a trip is made to the supermarket on a bicycle but the bicycle is used relatively less than on workdays. Lastly, a higher share of trips is made on foot on Sundays. This can be, because people tend to walk more in their leisure time or they take more time for a trip.

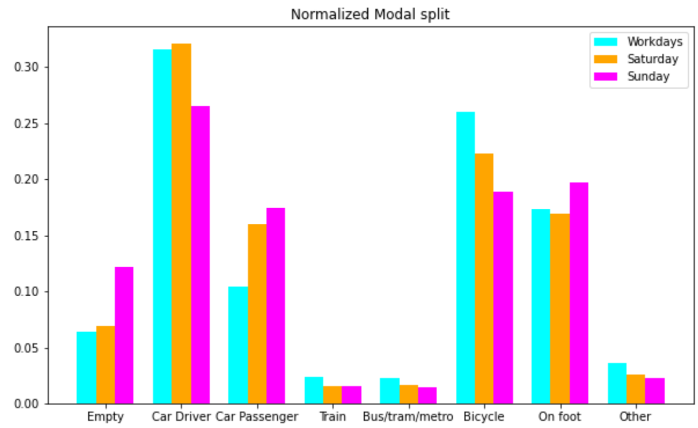


Figure 4.3: Percentage of modal split per workday, Saturday and Sunday

4.2.4. Prominence of tour-making behaviour in the weekend

A tour is a sequence of trips that starts and ends at the home location of a person. In a trip-based approach, trips are regarded separately, even when a trip is linked to another trip. As this research assumes that a trip-based model is suitable for a weekend model. It should be investigated if tour-making or trip-chaining behaviour is different in the weekend and if this behaviour is more present in the weekend.

Analysing individual tours of respondents in the ODiN dataset requires a complex data analysis approach. Individual tours have to be constructed from the single trips and it has to be known whether the start location of a trip was the home of the respondent or not. For now, this analysis was not done, but a simple approach was used. The trip purpose 'Going Home' was used to count the number of tours that people made. If a respondent went home twice, that respondent has made two tours. Next to this, the number of trips were counted per respondent to get a distribution of the number of trips that respondents made if they made a certain number of tours. This was used to determine whether tours are more complex in the weekend, as a higher number of trips means that different trip purposes were combined in one tour.

Figure 4.4 shows an overview of the percentage of the number of tours that were made on different days, or to be precise, the number of times that a respondent went home. It can be seen that there is a lower share of tours on both weekend days. Only on Saturday, a higher share of tours is made when three or four tours are made on a day. The figure also indicates the percentage when no tour/trip was made in the first three bars.

From the analysis into the tour length per number of tours it was found that there are only minor differences between the days. People tend to make slightly shorter tours in the weekend but this is not true for all tour lengths. From this, it can be assumed that tour formation is not more or less complex, supported by the fact that people make slightly less tours in the weekend.

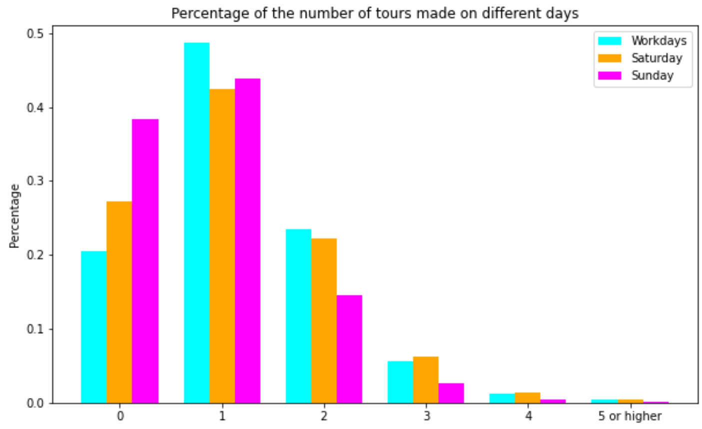
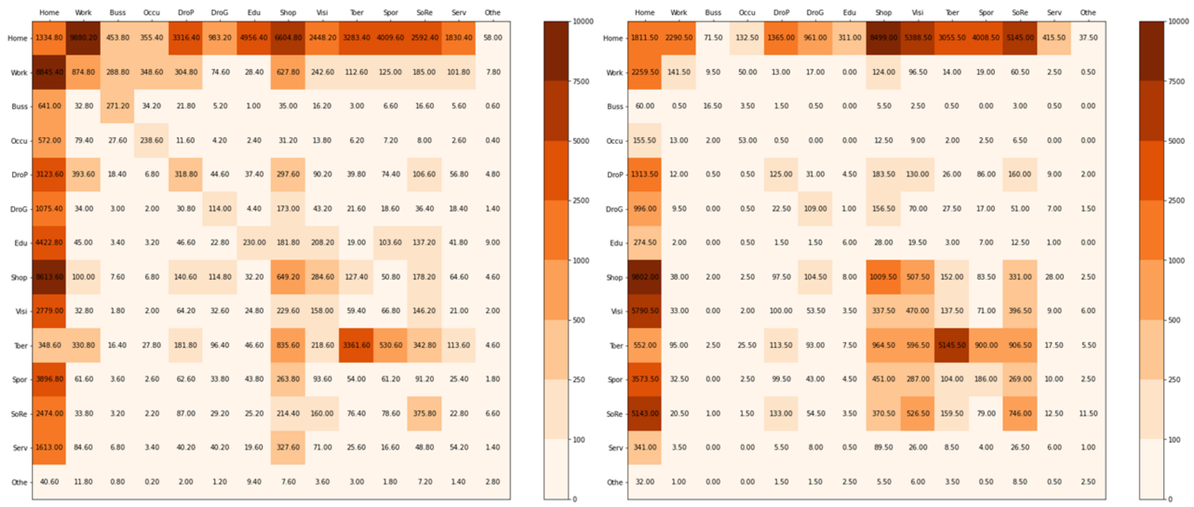


Figure 4.4: Percentage of tours per workday, Saturday and Sunday

4.2.5. Differences in consecutive trip purposes

A simplified way to analyse which types of trip purposes are performed in a sequence or trip-chain in the weekend is by looking at the trip purpose at the origin and destination of a trip. For example, if a person goes from home to the supermarket, the resulting sequence is a 'Home-Shopping' trip. This distinction allows for a more detailed analysis of a trip, as the previous trip purpose is included. This can highlight relations between trip purposes without analysing the complete trip-chain of a person. To visualise this, a heatmap was created to give an overview of the sequences in relation to each other. This can be seen in figure 4.5 in which a heatmap is shown for the average workday and average weekend days. The average was calculated by dividing the total number of trips per sequence by 5 or 2. The labels on the y-axis represent the departure purpose and the labels on the x-axis represent the arrival purpose. The top row of the heatmap thus represents all the sequence from home to work, education, etc. and the the lefmost column of the heatmap represents the sequences towards home. A non-linear color scale was created, so that the low values could also be distinguished.



(a) Workdays (b) Weekenddays

Figure 4.5: Heatmap of the number of trips per ODiN trip purpose sequence for (a) workdays and (b) weekenddays. The left column shows the departure trip purpose and the top row shows the arrival trip purpose

What immediately stands out in both heatmaps is that the sequences from and towards home have the largest magnitudes. Around 80 % of the trips is home-based so the rest of the trips are between out-of-home activities. The home-based sequences show differences between trip purposes that have been shown earlier, but it's interesting to note that the sequences are not symmetrical. 'Home-Shopping' has an average of 6600 reported trips per workday while 'Shopping-Home' shows an average of 8600 reported trips. The rest of the shopping trips come from 'Work', 'Shopping' or other purposes. Interestingly, 'Home-Work' shows a reverse relationship, as there are more trips towards work from home, then back. Apparently, people tend to perform an additional activity after work but this isn't true for shopping.

Other sequences that are present in a workday, show that trip purposes are combined from work towards the rest of the trip purposes. In a weekend day, the trip purpose work is barely combined with other trip purposes. It can be seen that this is mostly done between leisure-related trip purposes, which is an interesting observation on weekend travel behaviour.

4.2.6. Conclusion

This section set out to investigate differences between work- and weekend day travel from ODiN data. As a result, four characteristics were found in the data-analysis. The characteristics that were found in the data-analysis were compared to the differences and recommendations that were found in Chapter 2 and 3. It was found that the data-analysis didn't find any additional differences but it only highlighted the differences with travel data from the Netherlands or uncovered small details. The found characteristics are therefore linked to similar characteristics from the literature, as these differences do thus not require a specific adaptation. This overview can be seen in table 4.2. Additionally, argumentation is given below on why these characteristics were linked.

Table 4.2: Characteristics of work and weekend travel from ODiN data, linked to literature

Characteristic found in the ODiN data analysis	Similar characteristic in literature
D1: Trip purpose and modal split show similar differences as the literature.	C1: Different trip purposes have a higher share in the weekend, C9: Mode choice is different
D2: Trip-chains are between recreational or shopping purposes in the weekend, whereas work or school is the main activity in workday trip-chains.	C6: Larger difference in trip-chaining behaviour between people
D3: Differences in trip purpose aren't strictly between work- and weekend days but this also differs per day of the week.	R2: Time use during the week has an effect on time use in the weekend
D4: Saturdays differ from Sundays in trip purpose, modal split etc.	C2: Saturdays and Sundays show different travel behaviour

Characteristic D1 highlights the differences in trip purposes and modal split that were also found in the literature. Linking D1 to characteristic C1 and C9 is therefore trivial. Characteristic D2 describes a difference that is a part of characteristic C6. Although it is not directly described in C6, it was found in the literature that trip-chaining occurs between different trip purposes on weekend days. Subsequently, characteristic D3 can be related to R2 as D3 highlights that the trip purpose distribution can also differ per workday. This fits within R2 as this is about considering the dependencies of activities within an entire week, instead of only considering an average work and weekend day. Lastly, D4 can be linked to C2 as both characteristics describe that travel behaviour on Saturday is different from Sunday.

4.3. Saturday trip purpose distribution

Next to the general data analysis, the ODiN data was analysed to determine what trip purposes should be present in a Saturday transport model. To do this, the data was first filtered to exclude trips which aren't modelled or used in a transport model, this data is therefore not usable. After that, a Saturday trip purpose distribution is proposed, based on the trip purposes in ODiN. The new distribution is then compared on differences in modal split and the trip length distribution. This is investigated, as it is more sensible to create a Saturday model with trip purposes which show differences in travel behaviour between the trip purposes. Otherwise, the results of the model do not differ per trip purpose and the differentiation has no additional benefit.

The data is first filtered on trips which start and arrive at the same destination. These type of trips are hard to model in a transport model as there is no clear route which the respondents have taken, so it's impossible to correctly predict which route the respondent has taken. Consequently, the majority of these trips was made around the home by respondents who were walking or cycling so the impact on the transport system is minimal in general. Only in specific areas, such as an urban office district, where many people go for a walk around lunch time. It's possible that this type of trip has a temporary impact on the transport system but these kinds of problems occur very locally.

The result of excluding these type of trips is that a large share of the trip purpose 'Touring/walking' is removed from the data, which can be seen in figure 4.6, which had a share of around 10 % in the data. The remaining trips for the trip purpose 'touring/walking' were found to be trips towards a destination where people would go for a walk, a forest for example, or the beach. In the data, these kinds of trips were performed more often with the car, so it's important to include these in a transport model.

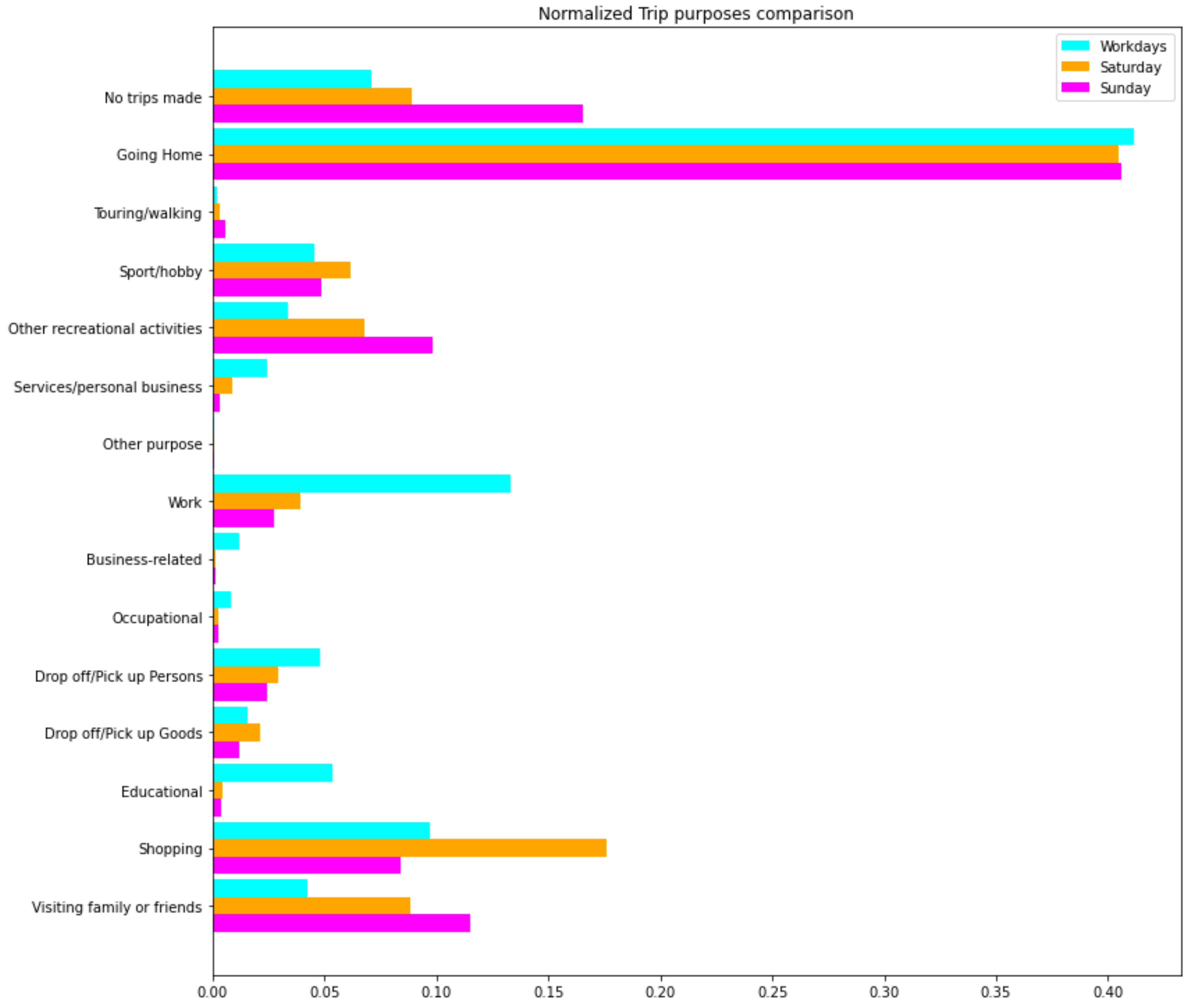


Figure 4.6: Percentages of ODiN trip purposes per workday, Saturday or Sunday

The next step was to remove the modes of transport from the data that aren't used in the model. The dataset consists of 24 different modes which can be divided into 7 categories from which the majority of modes fall under 'Other' or 'Bicycle'. An example of this is that a trip made with a camper, tractor or a boat falls under the category 'Other' and a trip made with a speedpedelec, e-bike or a moped falls under the category 'Bicycle'. The model uses three modes of transport which can be seen in table 4.3. Walking is present in the model as an access/egress mode for public transport and the car categories are combined into one in the model. The categories 'Walking' and 'Other' in the data are not in the model and are thus removed from the dataset. Trips made with these modes of transport are different than a trip made with a car or there is not enough data per mode to analyse what type of trips are made. Therefore the data is not added to other categories. Trips made with a freight truck are for example not comparable to car trips as a freight truck makes a lot of deliveries and thus follows a different travel pattern.

Table 4.3: Difference between the categories of modes in the ODiN data and the transport model

ODiN data categories	Model categories
Car driver	Car
Car passenger	Public transport
Public transport	Bicycle
Bicycle	
Walking	
Other	

4.3.1. Trip purpose distribution for a Saturday

Now that the data is filtered, a trip purpose distribution needs to be formed for a Saturday. As it's unknown from the literature what a good trip purpose distribution is. This research starts to include as many trip purposes as possible while still creating a valid model. This is done to include a diverse set of travel behaviour with different trip purposes. To do this, a first look is taken at the available data to do this, and thus also the major trip purposes on a Saturday. This can be seen in table 4.4. In the table, the number of data points per trip purpose are shown for workdays and Saturdays for the Netherlands and the province of Noord-Brabant. A major difference is that more data is available for the workdays, as this data is combined. This poses a first challenge for a Saturday model, as there is less data than for a regular Workday model. Next to that, the table shows that a small subset of the data is used to estimate the model itself. Note that the trip purpose 'Going home' is shown in the table, which changes the proportions of the trip purposes in comparison with the total number of trips.

A first step for the trip purpose distribution is to look at which trip purposes have too little data to become a single trip purpose. These can be combined with other trip purposes so that the data can still be used. Afterwards, it will be checked if this combination makes sense by comparing modal split and trip length distribution. If there is too little data, this effect is negligible and the trip purposes can be combined anyway.

Table 4.4: Sample size per ODiN trip purpose for the Netherlands (NL) and Noord-Brabant (NB) per workday or Saturday

ODiN trip purposes	Workdays NL (n)	Saturdays NL (n)	Workdays NB (n)	Saturdays NB (n)
1. Going home	169401	32723	24019	4485
2. Work	53881	3023	8174	448
3. Business-related	4899	100	810	13
4. Occupational	3314	199	68	24
5. Drop off/pick up Persons	19760	2454	2480	359
6. Drop off/pick up Goods	6443	1749	912	230
7. Educational	22877	361	2999	49
8. Shopping	40032	14348	5294	1859
9. Visiting family or friends	17257	7264	2750	1164
10. Touring/walking	799	293	87	36
11. Sport/hobby	19676	5155	2609	696
12. Other recreational activities	14141	5614	1954	786
13. Services/personal business	10147	735	1377	107
14. Other purpose	410	67	68	6
Total	383037	74085	54004	10262

Table 4.5 shows how the trip purposes that are defined in ODiN, are used to create trip purposes for a

workday model. In some models social-recreational trips are also modelled, otherwise they are used as 'other' trips. It can be seen that trip purposes 3 and 4 have less than 50 data points per trip purpose. In a workday model, these trip purposes are modelled separately in the trip purpose 'Business', as can be seen in table 4.5. For a Saturday, it is thus not sensible to model these trips separately. The trip purposes of these trips relates the most to work trips so they are combined in the purpose 'Work'. This and other changes to the coding of trip purposes for a Saturday model can be seen in table 4.6.

A large difference can be seen in the trip purpose Educational, between the workday and Saturday. The amount of data is too low to model educational trips separately for a Saturday. This type of trip can be work-related as people follow a course in the weekend but this doesn't mean that all educational trips are work-related in the weekend. It's also possible that someone follows a course which is not related to their job. Therefore, the educational trips are added to the 'other' trips for a Saturday model. The checks on modal split and trip length distribution will have to show whether the travel behaviour of educational trips is comparable to work trips or not.

The trip purposes Shopping, Visiting family or friends, Other recreational activities and Sport/hobby all have a substantial amount of data. Next to this, these trip purposes are characteristic for weekend travel. Although only shopping trips were modelled separately in a workday model, all these trip purposes can be treated separately. The aim of this analysis is too include as much trip purposes as possible and it can be decided in a later step whether it's possible to model these trip purposes or if there is an actual difference in travel behaviour between these trip purposes.

Table 4.5: Coding of ODiN trip purposes for a workday trip purpose distribution. **Sometimes coded as SocRec*

ODiN trip purposes		Workday trip purpose distribution
2. Work	→	1. Work
3. Business-related	→	2. Business
4. Occupational	→	2. Business
5. Drop off/pick up Persons	→	5. Other
6. Drop off/pick up Goods	→	5. Other
7. Educational	→	4. Educational
8. Shopping	→	3. Shopping
9. Visiting family or friends	→	5. Other*
10. Touring/walking	→	5. Other*
11. Sport/hobby	→	5. Other*
12. Other recreational activities	→	5. Other*
13. Services/personal business	→	5. Other
14. Other purpose	→	5. Other

A little amount of trips remains for the trip purpose: 'Touring/walking'. This type of trip fits best as a social-recreational trip, as people go for a walk to relax or to enjoy nature. This is also done with other people and therefore it also has a social aspect. The trip purpose 'Touring/walking', could also fit to the purpose: 'Sport/hobby'. Walking or touring can also be seen as a sport or hobby but it depends on more aspects which trip purpose fits the activity. For example if someone exercises on a road bike, this is a tour that is made outside but the goal of the activity is the sport itself. This is different then when people go for a walk at lunchtime, then the activity is focused on recreating. It is assumed that an activity like exercising on a road bike is categorised as a Sport/hobby trip instead of touring/walking. Touring/walking is therefore combined with the social-recreational trip purpose.

There are two trip purposes which describe the delivery or collection of people or goods. Separately, these purposes are probably too small for a model but they can be combined together. The purposes mostly vary in the type of destinations, where picking up people in the weekend is done from a train station or someone else's house. For goods, destinations can vary between shops, parcel lockers or a home address where a second-hand item is bought. It is also assumed that these trip purposes are similar in terms of modal split and trip length distribution, presenting a good argument to combine them in one purpose.

The remaining trip purposes are: Educational, Services/personal business and trips with an unknown/other purpose. These trip purposes are not characteristic for weekend travel and the amount of data is low to form a separate category. Therefore, these trip purposes are combined into the purpose: Other.

Table 4.6: Proposed coding of ODiN trip purposes for a Saturday trip purpose distribution

ODiN trip purposes		Saturday trip purpose distribution
2. Work	→	1. Work
3. Business-related	→	1. Work
4. Occupational	→	1. Work
5. Drop off/pick up Persons	→	6. Drop off/pick up
6. Drop off/pick up Goods	→	6. Drop off/pick up
7. Educational	→	7. Other
8. Shopping	→	2. Shopping
9. Visiting family or friends	→	5. Visits
10. Touring/walking	→	3. SocRec
11. Sport/hobby	→	4. Sport
12. Other recreational activities	→	3. SocRec
13. Services/personal business	→	7. Other
14. Other purpose	→	7. Other

The result of this analysis is the coding of ODiN trip purposes into a set of seven trip purposes that can be used to create a Saturday model. An overview of this can be seen in table 4.6. The coding is different from the traditional coding for a workday model where the emphasis is on work and school trips and a majority of the trips would be under other trips, especially if the recreational trip purpose is not modelled separately. For the Saturday, this emphasis shifts to shopping trips and the different leisure purposes that are present in the weekend. This difference can also be seen in figure 4.7 and 4.8. The rest of this section will show whether the proposed trip purpose distribution is valid for a Saturday. Another important note with these figures is also that the share of a trip purpose is not determinative for it's relevance in a model. Business trips are usually modelled in a workday as they have an effect on the morning peak, even when the share of business trips is relatively low when compared with the share of recreational trips. Next to this, it's difficult to derive from this figure whether recreational trips should also be split into multiple trip purposes for a workday model.

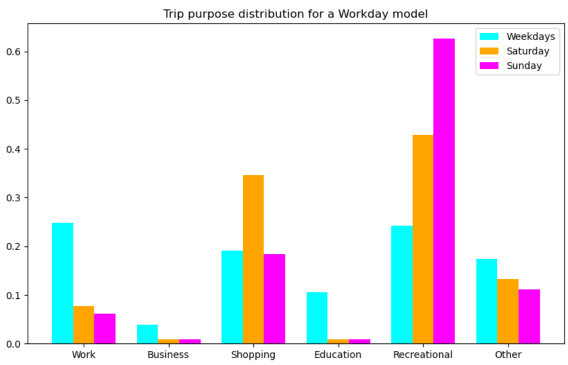


Figure 4.7: Workday trip purpose distribution in percentages
**Recreational sometimes included under Other*

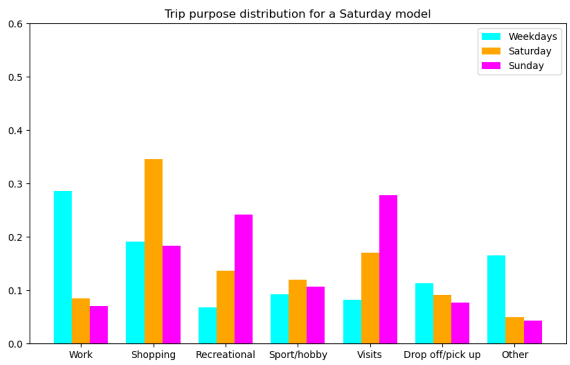


Figure 4.8: Saturday trip purpose distribution in percentages

4.3.2. Modal split per Saturday trip purpose

As indicated in the introduction of this section, it is important for a transport model that there are differences between the trip purposes in a model. Therefore, the proposed Saturday trip purposes are analysed on their modal split. This can give general insights on the preferences for certain modes per trip purpose and to uncover if there are no big differences in the trip purposes that are combined.

Table 4.7 shows the trip purposes from ODiN, grouped in the Saturday trip purpose distribution. For this comparison, more modes are shown to show these differences per trip purpose. First is the purpose work, there are small differences between the percentage of car drivers and the share of car passengers is low. The only substantial difference is the difference in bicycle use for business-related trips. The social-recreational trip purpose has a notable difference in Public transport use, apparently social-recreational destinations are reached more via public transport than destinations for Touring/walking. Drop off/pick up trips are made mainly via car, this is more convenient than the bicycle. The largest differences between the ODiN trip purposes are within the trip purpose: 'Other'. This is a purpose where the remaining trips are combined so it's not preventable that these differences occur. Interestingly, educational trips have a high share of public transport use on a Saturday. This can either be explained by the fact that these destinations have good accessibility on a Saturday or the user has a preference for public transport on this trip. Although it's good to check that there are no large differences within a trip purpose. Some trip purposes have little data, making their effect negligible on the resulting trip purpose.

Table 4.7: Modal split for ODiN trip purposes with corresponding Saturday trip purpose in percentages across a row

Saturday Purpose	ODiN Purpose	Car driver (%)	Car passenger (%)	Train (%)	Bus/tram (%)	Bicycle (%)
1. Work	2.	57,8	6,9	1,4	0,8	33,0
	3.	68,7	9,8	1,4	0,0	20,1
	4.	63,8	2,8	0,0	0,0	33,4
2. Shopping	8.	50,8	17,9	0,5	0,6	30,2
3. Socrec	12.	32,4	36,8	3,6	2,8	24,4
	10.	50,2	33,9	0,0	0,0	15,8
4. Sport	11.	32,9	28,3	0,6	0,2	38,0
5. Visits	9.	44,6	29,4	2,6	0,4	22,9
6. Drop off/pick up	5.	75,3	17,0	0,5	0,1	7,0
	6.	65,2	16,5	0,7	0,3	17,3
7. Other	7.	38,2	31,9	9,0	2,4	18,4
	13.	56,9	19,5	1,6	0,0	22,0
	14.	44,1	27,8	3,9	2,4	21,7

It's more interesting to compare whether the Saturday trip purposes show differences between them in modal split. The resulting modal split per Saturday trip purpose is shown in table 4.8. Note that a mode such as car passenger will be combined into the mode car. This reduces differences in the modal split per trip purpose but these differences are reflected in attributes in the model, such as the car occupancy rate per trip purpose.

At a first glance, the modal splits are different between the trip purposes and the differences seem explainable by the trip purpose itself. Work trips have a low rate of car passengers and a relatively high share of bicycle use when compared to the rest. Shopping trips have a higher car passenger percentage than work trips and low public transport use. For work and shopping trips it is obvious that these are different types of trips but for leisure trips, this is less clear.

Table 4.8: Modal split for Saturday trip purposes in percentages across a row

	Car driver (%)	Car passenger (%)	Train (%)	Bus/tram (%)	Bicycle (%)
Work	58,4	6,6	1,3	0,8	32,9
Shopping	50,8	17,9	0,4	0,6	30,2
SocRec	33,2	36,6	3,4	2,7	24,0
Sport	32,9	28,3	0,6	0,2	38,0
Visits	44,6	29,4	2,6	0,4	22,9
Drop off/pick up	71,2	16,8	0,6	0,2	11,2
Other	47,8	25,4	4,0	1,5	21,2

The social-recreational, sport and visits trip purpose have a very comparable modal split but there are minor differences like higher public transport use for social-recreational trips and there are differences in car passenger rate between the leisure trip purposes. Intuitively, these differences are caused by the destinations that people visit and with whom they do this. Social-recreational trips are done with a group of friends or family which travel together to their destination. These destinations are located in city-centres so therefore the use of public transport is higher as it's more convenient. Sport trips are made with a sports team to neighbouring villages, these trips are often made together. Next to this, people travel to their local sport location, explaining the higher bicycle use. Visits are trips to home-locations with family or friends, this can be far away or close-by. The underlying behaviour of the leisure trip purposes can thus explain the differences in modal split and why they should be regarded separately.

Lastly, the trip purpose drop off/pick up is different from the rest of the trip purposes and this is logical, as the car is the most convenient mode of transport. The trip purpose other is a collection of trip purposes, making it difficult to underpin the underlying behaviour. When the modal split is compared with figure 4.3, the modal split of other trips seems comparable to the general weekend modal split.The Saturday trip purposes thus differ in modal split, although the differences are small for the leisure trip purposes. These differences can be explained by the underlying behaviour per trip purpose.

4.3.3. Trip length distribution per Saturday trip purpose

Next to the modal split, the trip length distribution is an important indicator to check how travel behaviour differs between trip purposes. Some trip purposes have a higher share of shorter trips and these are differences that should be reflected within the transport model itself.

Table 4.9 shows the average trip length per trip purpose for the Netherlands (NL) and the province of Noord-Brabant (NB). The mean trip lenghts give an idea about the differences in travel behaviour per trip purpose. Next to this, the mean trip-length in Noord-Brabant is higher for all trip purposes, indicating that the region has an effect on travel behaviour and that a countrywide statistic is not applicable to specific regions.

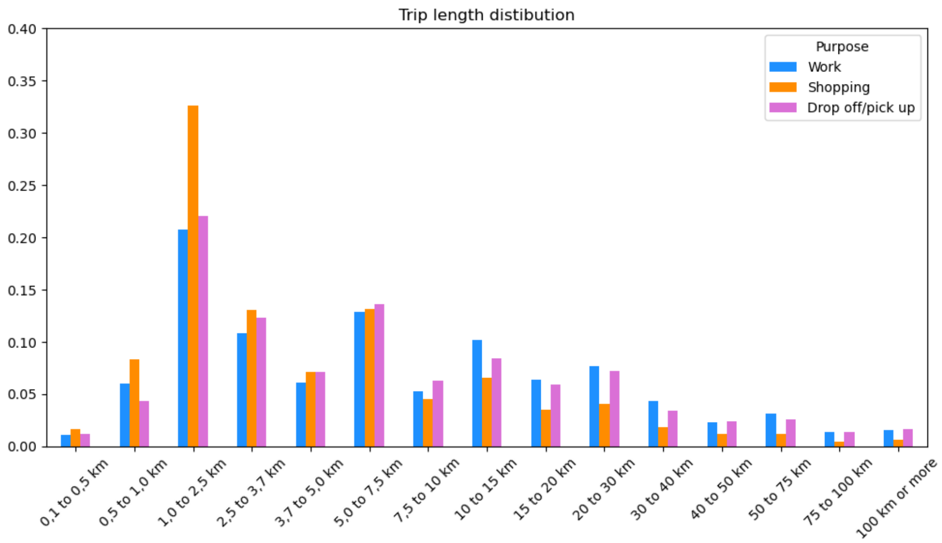
Table 4.9: Mean trip lengths per Saturday trip purpose distribution for the Netherlands (NL) and Noord-Brabant (NB)

	Mean NL (km)	Mean NB (km)
Work	13,76	17,00
Shopping	7,72	8,79
Socrec	26,77	33,22
Sport	20,18	25,06
Visits	12,40	16,30
Drop off/pick up	13,10	17,35
Other	14,96	21,19

A better way to analyse how trip lengths differ per trip purpose is by looking at the differences between the distance bins. This can be seen in figure 4.9 and 4.10. Figures per ODiN trip purpose which also show differences between weekdays, Saturdays and Sundays can be seen in Appendix C. Figure 4.9 shows a trip length distribution for three trip purposes which have a low mean trip length. It can be seen that especially shopping trips are characterized by a high share of short trips and a lower number of long trips when compared to the other two trip purposes in the figure. Intuitively this is logical, but it would also be interesting to know whether there is a difference in the type of shopping trip that is made on short or medium distances. Such a difference, could further clarify Saturday travel behaviour. Differences between Work trips and Drop off/pick up trips are smaller and don't show any significant differences. Other than that, it is interesting that drop off/pick up trips are longer than 75 km on a Saturday. This is probably caused by the tendency of people to travel further on weekend days. This observation is confirmed in a comparison between ODiN trip purposes in appendix C.

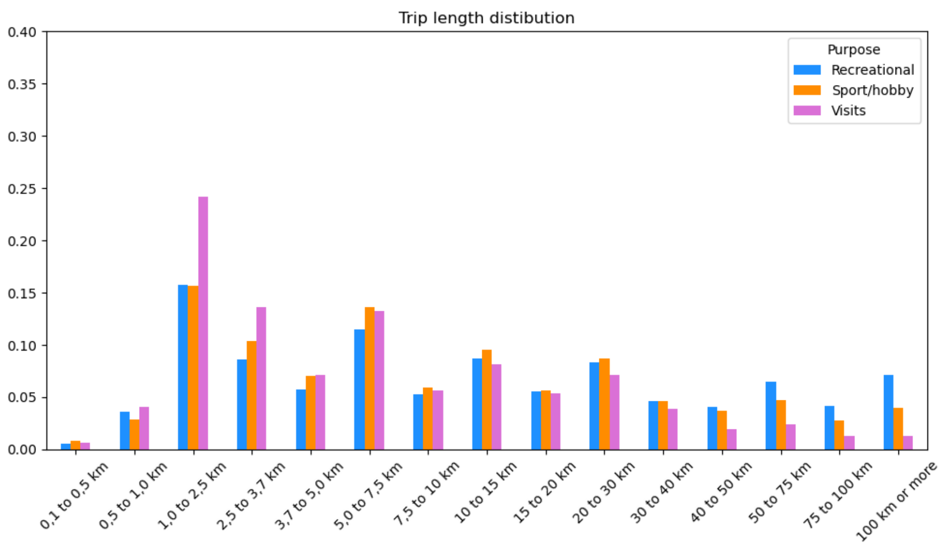
A comparison of the leisure trip purposes can be seen in figure 4.10. Visit trips have a higher share of shorter trips than the social-recreational or sport trips. This can be explained by the fact that relatives or friends can live close to each other and that these trips are thus shorter in general. Social-recreational

Figure 4.9: Trip length distribution in percentages per Saturday trip purpose Work, Shopping or Drop off/pick up



and sport trips seem to have a very similar trip length distribution but the main difference exists for the trips longer than 50 km. It is difficult to explain where this difference comes from as many aspects can influence the purpose of a trip or the destination. The travelled distance is then a result of these combinations. It is therefore also possible to combine the social-recreational and sport trips into one purpose as the differences are very small.

Figure 4.10: Trip length distribution in percentages per Saturday trip purpose Socrec, Sport and Visits



Based on the shown trip-length distributions, the differences between trip purposes can be marginal. Some trip purposes do have a unique distribution but some trip purposes could be combined as the differences are small. Next to this, it is difficult to infer if these marginal differences stem from general Saturday travel behaviour or from the trip purpose itself.

4.4. Conclusion

This chapter set out to partially answer sub-question 1: *What are travel patterns and characteristics of travel on a Saturday in comparison with a regular weekday and Sunday?*. By investigating the differences in work- and weekend day travel. This didn't result in an additional set of differences but the differences that were found, highlight the findings in the literature from Chapter 2. The data analysis thereby enriches the answer to sub-question 1 by providing a more detailed analysis into differences in trip purpose between all days of the week, modal split and trip-chaining behaviour. Table 4.10 then shows the characteristics from the data-analysis, which are linked to the characteristics from the literature.

Table 4.10: Characteristics of work and weekend travel from ODiN data, linked to literature

Characteristic found in the ODiN data analysis	Similar characteristic in literature
D1: Trip purpose and modal split show similar differences as the literature.	C1: Different trip purposes have a higher share in the weekend, C9: Mode choice is different
D2: Trip-chains are between recreational or shopping purposes in the weekend, whereas work or school is the main activity in workday trip-chains.	C6: Larger difference in trip-chaining behaviour between people
D3: Differences in trip purpose aren't strictly between work- and weekend days but this also differs per day of the week.	R2: Time use during the week has an effect on time use in the weekend
D4: Saturdays differ from Sundays in trip purpose, modal split etc.	C2: Saturdays and Sundays show different travel behaviour

Furthermore, this chapter proposes a Saturday trip purpose distribution which consists of the purposes: Work, Shopping, Social-recreational, Sport, Visits, Drop off/pick up and Other trips. This was formed, based on the share of the ODiN trip purposes and an analysis was carried out to compare the modal split and trip length distribution for the proposed Saturday trip purposes.

5

Weekend model purpose and use cases

Understanding the wishes and requirements of model users and practitioners in the field of transport modelling is an integral part of the development of a model. Different models can have different use-cases or purposes. These aspects of a model can vary per user and this can have an effect on the required data for a model or the desired level of detail. Chapters 2 and 4 have already shown that travel in the weekend is different from regular workdays and that there has been a limited effort to develop transport models specifically for the weekend. Due to the different nature of weekend travel, and a lack of applied models. It is sensible to first investigate the possible applications of a weekend model. Without a clear purpose for a model, model development is a costly process which takes a lot of time. Alternatively, the purpose of a model defines what the outcome of the model should be and this should also align with the potential users of the model. Therefore, this research wants to answer sub-question 2 in this chapter:

3. What is the use-case and purpose of a Saturday model for governments and traffic planners?

First of all, this sub-question is answered by holding interviews with practitioners about possible use-cases and purposes of a Saturday model in section 5.1. The outcome of these interviews is used to define the purpose of a weekend model and possible use cases. These can be used as a recommendation for the possible model adaptations in Chapter 6, or as an initial view on how a Saturday model should be developed. Next to the interviews, the literature review and talks at Goudappel provided extra information in section 5.2 on possible model use-cases but also on other factors that are important to consider before model development such as the policy implications of a weekend model. Before the conclusion, section 5.3 summarizes the results from the previous sections and the chapter then concludes in section 5.4.

5.1. Interviews

To better understand what the use and purpose is of a Saturday model. Interviews were held with municipalities and regional governments. The interviews will be used to identify the purpose of a weekend model and to enquire if there is a need for these kind of models. Additionally, the interviews can reveal specific traffic or travel relations of the weekend which only occur on a local level. The interviews will be semi-structured to leave room for an open discussion on the subject.

The following questions were prepared for the interview, the full interview script can be seen in Appendix A.

1. What goals are applicable to the weekend?
2. What would weekend-specific goals be?

3. What are travel/traffic characteristics of your municipality or destinations that are important to know about when creating a transport model for the weekend?
4. How can a weekend transport model be useful in general?

The first two questions are meant to ask the respondent about what kind of goals there are, and in what way these are applicable to the weekend. These goals can be to promote cycling or to improve the quality of the transportation system. Governments use these goals to steer policy development in a certain direction so that these goals can be used for multiple projects. It would be interesting to know if the interviewees identify different goals for the weekend than on workdays or to know what these goals could be. The third question is then a specific question to investigate if the interviewee recognizes differences between travel behaviour in work and weekend days in the local transport system of the interviewee. Capturing these differences is interesting for the potential use cases of a model and to know if these differences are observed by the interviewee. Lastly, question four aims to understand what the interviewee thinks about the purpose of a weekend model.

Possible candidates for the interview were approached through contacts from Goudappel. These contacts work with transport models that Goudappel provides so the candidates have basic knowledge about how a transport model works and how it is used to support policy development. After an interview is scheduled, the interview script is sent to the interviewees so that they have an idea of the questions in the interview. After the interview, an interview summary will be constructed from the transcript. The interview script and the interview summaries can be found in Appendix A The following subsection provides a summary from the interviews and gives a reflection on the outcomes.

5.1.1. Interview summary

Four interviews were held with people from local and regional governments. Each of the interviewees either oversees how the transport model is developed so that it can be used for different purposes or they work with the results of the model. The interviewees don't work on the model itself by developing a new version or a different component. It's assumed that the interviewees thus have a reasonable understanding of what a transport model is and that they have worked with both model developers and policy makers to acquire relevant results from a transport model. The rest of this section shows the outcomes of each interview question. Summaries of the interviews can be seen in appendix A.

1. What goals are applicable to the weekend?
Currently, the weekend is not regarded separately in policy development so there are no specific goals for the weekend. Several interviewees mentioned that this is because there are no specific problems that occur in the weekend. Therefore, there is no reason to create separate goals for the weekend, as there are no problems to solve. This doesn't mean that these problems aren't there in the weekend. Traffic intensities in the weekend are not necessarily lower than on workdays so the interviewees emphasized that it's reasonable to think that problems occur in the weekend and that this requires a separate set of goals.

Although it was mentioned that there are no specific problems for the weekend, one of the interviewees acknowledged that there was a situation in which a possible future problem was investigated for the weekend. This situation occurred as part of a larger plan. The city of Den Bosch has recently made the choice to drastically change the transport network in the city. By discontinuing the inner ring road in the city and diverting cars to the outer ring road, more houses will be built in the city centre but this area has to remain accessible and liveable. The current plan prevents nuisances by car traffic in the future and makes more space for cyclists and a greener city, additionally improving the well-being of citizens. In the development of this plan, the impact on traffic in the weekend was investigated, as retailers were afraid that people couldn't reach the city centre any more. A study into the new plan showed that this wasn't the case. The interviewee mentioned that for these kind of problems it would be good to think about separate goals for the weekend.

2. What would weekend specific goals be?
The interviewees mentioned a variety of goals but they also acknowledged that the goals are confined to the goals of the organisation. The task of a government can be to maintain a road and the corresponding goals are then limited to that task. This and the lack of problems in the weekend makes it hard to think about weekend-specific goals. Still, the interviewee who mentioned this, also says that this might

become relevant in the future.

Other interviewees mentioned goals which could be focused on the weekend. This was highlighted in the plans of Den Bosch. In that plan, decisions are made about which modes of transport are prioritized in certain places. These decisions come with goals such as keeping the city centre accessible, liveable or having adequate parking facilities. It was mentioned that a weekend-specific goals could be that traffic lights have a different configuration which is fit for weekend traffic to facilitate peak flows around the city centre. As there is no space for extra infrastructure, the existing infrastructure has to be utilised in a smart way so a dynamic configuration of traffic lights could be a suitable solution. These goals were also mentioned by another interviewee. The city of Zwolle is undergoing a similar transition as Den Bosch. In the new situation, there will be less capacity for cars on some roads, so the interviewee mentions that it becomes an interesting challenge how this new situation translates to the weekend and what goals should be developed in line with this plan.

3. What are travel/traffic characteristics of your municipality or destinations that are important to know about when creating a transport model for the weekend?
On a regional scale, the interviewees mentioned that it is important to consider the impact of freight traffic. On some regional corridors, there is a high percentage of freight traffic on workdays. In the weekend, this is not there, so this can cause large differences. Other than that, the roads between cities are busy in the weekend but no particular places or bottlenecks stood out on a regional scale.

On a local scale, it was highlighted that weekend-related traffic can be seen around city centres, in the sense that there is sometimes more traffic in the weekend than on a workday. This effect can also vary per month as a lot of people tend to go shopping in December or January and other months attract different types of visitors. One of the interviewees mentioned that in the case of a large event venue, it differs per event if this causes notable problems. For some events, a lot of people arrive by car at the same time, while for others this is spread out over the day, or the amount of people that arrives via public transport differs. The interviewee mentions that it's therefore difficult to say if this is a weekend-related problem as these things can also happen on a Thursday or a Friday. Another interviewee mentions that there is a lot of traffic in places where traffic is expected in the weekend. Such as, hardware stores, furniture stores or specialized stores such as IKEA or Intratuin. These are places where people not only go to go shopping but also for the activity of being there.

4. How can a weekend transport model be useful in general?
The interviewees identified different purposes and use cases for a weekend transport model. Many mentioned that it would first be interesting to know what insights a weekend model can bring, before considering how it can be used for policy development. It was mentioned that the extra understanding of weekend travel is interesting but the next challenge would be if a policy should be made specifically for the weekend. Especially when the policy relates to the infrastructure, it will be difficult to say if something has to be adapted only for the weekend. Therefore, some interviewees highlight that the purpose of a weekend model might be very limited. An important argument for this is that transport networks are usually robust enough to handle typical weekend traffic and it is thus unrealistic and costly to develop a separate model as one of the interviewees highlights that it's likely that the weekend doesn't require any additional infrastructure.

One of the interviewees also identified a different use case. That is to develop a weekend model to be able to better predict the impact of traffic on the environment. Currently, this is done with a weekday transport model from which traffic flows are calculated for the weekend. Specific weekend travel behaviour is thus not present in these calculations and a weekend transport model can improve this. The interviewees also mentioned that the scale level of problems can be different for regional or local governments. Municipalities look at more detail at the city centre, while this is not important for regional governments. Therefore, a different purpose could be derived from a weekend transport model at different levels of detail.

Another possible use case of a weekend model can be to investigate the difference between weekend and workday traffic flows. It was mentioned that the traffic infrastructure in a city is now optimized to handle workday traffic but it is possible that the weekend requires a different setup in terms of traffic lights or junction configuration. Only if there is a big difference between workdays and the weekend, such changes to the infrastructure can be justified. One of the interviewees also mentioned that people complain less about traffic delays in the weekend, compared to workdays.

5.1.2. Reflection on the interviews

The interviews posed some interesting use cases for a weekend transport model but the interviewees were also unfamiliar with the subject in the sense that they rarely encounter situations in their work which are about the weekend. The interviews can therefore not be used with the prepossession that the respondents had a good view on the subject but that it's possible that they missed important aspects. Altogether, the outcome of the interviews is useful for this research but a larger group of interviewees is required to confirm the findings of this research.

The interview meant to ask the respondents about transportation goals that were applicable to the weekend but the responses were very problem-oriented. This doesn't mean that the respondents don't work from goals as many municipalities have a vision document which list the goals for the next couple of years. It could be that the work of the interviewees is not directly related to these goals and that the answers were therfore focused on problems. It would still be interesting to know whether the weekend requires different goals, such as the accessibility of recreational facilities in a municipality or how reduced public transport services relate to this. This is of course a much broader viewpoint than considering if a transport system has minimal congestion. This broader viewpoint of how a transport system affects everyone and how accessible it is, is a recent development. Consequently, this change of perspective might also make the development of a weekend model more relevant in the sense that the weekend could be regarded separately.

An interesting observation was made by one of the interviewees about how people perceive traffic delay in the weekend. It was mentioned that people complain less about delay in the weekend as people expect that it's busy when everyone goes home at the same time after a day of shopping. It's possible that people understand that the delay is only temporary, this could imply that the value of travel time is lower for people in the weekend.

Lastly, from this set of interviews it's hard to conclude what the purpose of a weekend model can be. A few use cases are identified which are interesting but the real purpose of a model lies in how it can be used in policy development. To uncover this, it should be investigated if a difference should be made in policy development for work and weekend days. From a travel behaviour viewpoint, this can be a logical distinction. Travel behaviour between these days is different and therefore different policy measures should be made for the different days. From a different viewpoint, this reasoning might not be logical at all and the observable effect of differences in travel behaviour might not be that large. Transport networks function in the same way in the weekend, apart from a few differences. The supply of transport is thus the same but the question is to what extent there is a mismatch between demand and supply in the weekend.

5.2. Model use cases from literature

The interviews have created a first view on what the purpose and use case of a weekend model can be. This section expands on that analysis by reviewing literature which discuss the possible purpose and use case of a weekend model. Relevant literature was found when searching for literature on weekend models in general in chapter 3.

Apart from the literature, another way ton include a Saturday model in policy development was discussed by talking with mobility experts from the company. As was discussed in the previous section, it is unclear how a Saturday model should be used in policy development in comparison with workdays. A general rule of thumb could be that a Saturday model is used when the traffic situation on Saturdays surpasses the traffic situation on a workday. The question is, in how many situations this will be the case or whether this is only applicable for specific use cases. Still, such a general rule of thumb could be a first criteria to use a Saturday model, although it is probably more desirable to define a set of criteria which not only considers peak traffic conditions.

In research by R. Liu et al., 2010, a survey was carried out under 20 Metropolitan Planning Organisations (MPO's) in and around the state of New Jersey. The goal of the survey was to collect information on how the weekend is treated currently and if the organisations had future plans to create weekend transport demand models. This resulted in a mixed response where some MPO's saw the necessity to create a weekend model and to include the weekend in future surveys to better understand the differences in work and weekend day travel. Other organisations didn't saw the need to do so as the weekend didn't cause any problems at the moment or there was a lack of funding. The organisations that were confronted with problems were situated in large metropolitan areas.

One use case that was identified in this research was the estimation of air quality in the weekend (R. Liu et al., 2010). Air quality would sometimes be the worst on weekend days so this was reason for some MPO's to predict the difference between work and weekday travel in a model. This was mainly done by applying a factor to weekday travel to calculate weekend travel. The MPO's acknowledge that this approach can only be used to predict traffic intensities in the weekend but not the underlying travel behaviour. It was identified that a better way to predict traffic emissions could be to use a traditional four-step transport model.

The research has also discussed the impact of special traffic generators on both workday and weekend travel and how this can be modelled. Airports, hospitals, universities, football stadiums or city centres all produce or attract a different volume of traffic than for example a regular neighbourhood. Because of this, it is needed to include these special generators in a transport model. Consequently, the research identifies that a use case of a weekend model can be to focus on such a special generator as that is where problems occur in the weekend. R. Liu et al., 2010 further mentions that modelling such a special generator could require specific trip generation rates which can be based on observed traffic flows or on explanatory variables.

Lastly, R. Liu et al., 2010 asked the MPO's how they would develop a weekend transport model and which components would be different from a weekday model. It was suggested that a factor approach, as was found in Oliver and van Vuren, 2010, is probably the most cost-efficient method to construct a weekend model, but this method lacks the key differences in travel behaviour which are found in the different destinations and time constraints of weekend travel. The main response was that a four-step model would be the best option for a first weekend model. The model would then require different trip purposes and most of the changes in the model would need to be done for the trip generation and mode choice component. A few MPO's mentioned that a tour or activity based model would have a better ability to capture weekend travel than a four-step model but it's difficult to conclude if this outweighs the increased cost and effort to make such a model. Next to that, it requires more data and some MPO's don't use the activity-based model, making it unlikely that they will implement it. The conclusion of R. Liu et al., 2010, is that it comes down to what the model needs to do. Based on that, a modelling approach can be chosen which suits the intended use of the model. In addition to this, Oliver and van Vuren, 2010 concludes that a factor approach can provide a quick and easy approach if this is required to asses the impact of a certain policy on the weekend.

5.3. Overview of use cases for a weekend model

Section 5.1 and section 5.2 have given possible use cases for a Saturday model, this section gives an overview of the use cases that were found, and which things have to be changed in a model to facilitate the use case. It can be taken from the use cases that they all require a basic Saturday model to function. Only use case M1 requires minor adaptations of the basic model to facilitate an analysis of the use case.

M1 *The use case of a weekend model can lie in specific locations where there is a special traffic generator which attracts traffic on a regular basis.*
Some locations such as a popular city centre, an event venue or a sports stadium attracts a large quantity of traffic on a regular basis. A weekend model could then be used to predict the amount of traffic that is generated to these specific locations, on top of regular Saturday traffic. The location should be studied in detail to asses the quantity of traffic that is generated, where it comes from and how the traffic is distributed in time. This information can then be used to model the scenario in detail.

M2 *A use case of a weekend model is to predict emissions and noise pollution on weekend days.*
A detailed prediction of emissions or noise pollution can be required in some areas by governments or institutions. A weekend model can assist in such a case by predicting traffic intensities per road. The validation of the model would then also require a set of measured traffic intensities

per road and vehicle type, next to travel demand data. The vehicle type is needed to validate that the share of freight travel is comparable to the share of freight travel in the model on that road,

M3 *A use case of a weekend model can be to compare traffic flows on work- and weekend days.* Measuring traffic intensities on Saturdays can only give a limited view of the traffic situation on a network. A Saturday model could be used to calculate the traffic intensities on a network and compare this with a workday model. This comparison can have applications in traffic management strategies, for example when a main road through a city is closed, a Saturday model can predict which detours people are likely to take.

Consequently, this overview shows that each use case is focused on a different model outcome. Assuring that a Saturday model thus produces accurate results, requires a specific validation of the results per use case.

5.4. Conclusion

The goal of this chapter was to answer the question what the purpose and use case of a Saturday model is for practitioners. In general, the purpose of a Saturday model lies in use cases where it is clear that the model can assist in policy-related problems. If the added value for new policies is unclear, it should first be investigated how the weekend should be treated in comparison to the rest of the week or if this distinction is not necessary at all. This leaves a gap in the question what the purpose of a Saturday model is, as it is uncertain whether a Saturday model can adequately assist in specific use cases. The investment in a model might not return a clear answer for policy-makers so this sub-question can't be fully answered in this chapter. A contradictory method to fully answer this sub-question would be to make a weekend model to asses if the model can fulfil it's intended purpose. The main goal of this thesis is to develop a preliminary model, so this sub-question might be answered later in this research.

What is certain from the use cases that were discussed in this Chapter is that they all require a basic Saturday model to function, only one of the use cases would require adaptations to the model, while all use cases would require their own set of validations to assure that the model is accurate for the specific use case. The purpose of a Saturday model can thus lie in specific use cases, this can either be in places where traffic is generated on a regular basis by a special attraction, such as a city centre, or a use case can be to predict emissions of traffic. Alternatively, this chapter found model specifications that are important to consider for the development of a weekend model. The use cases from section 5.3 are listed in table 5.1.

Table 5.1: Model use cases and recommendations from literature and interviews

	Model use cases and specifications
M1	The use case of a weekend model lies in specific use cases where there is a special generator which attracts traffic on a regular basis.
M2	A use case of a weekend model is to predict emissions and noise pollution on weekend days.
M3	A use case of a weekend model can be to compare traffic flows on work- and weekend days.

6

Adapting a workday model into a Saturday model

Creating a Saturday model does not necessarily require a different modelling paradigm but it can be done by adapting an existing model. First of all, Chapter 2 shows the key differences in travel behaviour between work and weekend days which is mainly caused by the different temporal constraints that people experience in the weekend. Chapter 3 then shows how the characteristics of weekend travel can be modelled within a trip-based four-step model by proposing a set of adaptations. It was found that adapting trip purposes and the trip generation step of the model is a crucial first step to create a weekend model. Next to that, the data analysis in Chapter 4 confirms the differences in travel behaviour and a separate analysis shows which trip purposes can be used in a Saturday model. Lastly, Chapter 5 shows that either the four-step modelling framework or an activity based model can be used to create a Saturday model. The chapter also shows a set of possible use cases for a Saturday model. Based on these analysis, it is difficult to conclude what an ideal Saturday model can be and what modelling paradigm should be used to do so. Alternatively, the analysis will be used to identify what adaptations are required to make a preliminary Saturday model, which is done to answer the main research question:

How can the BBMA model be adapted into a preliminary Saturday transport model?

The Chapter is structured in the following way. Section 6.1 shows how the BBMA model works technically. This is the base model which is used in this research to apply the model adaptations. Section 6.2 describes in detail which adaptations are selected to create a Saturday model and how these adaptations change the model technically. To keep an overview, different model versions are created so that the impact of different modelling adaptations can be measured between different versions. Lastly, section 6.3 shows how the different model versions will be compared.

6.1. Overview of the BBMA model

This section will present an overview of the model setup of the BBMA model. This is done for future reference of the components of the model, and to differentiate between choices that were made in this research and in the development of the BBMA model. This section first presents an overview of the model itself and the different variables and categories that are used. After that, the trip generation component of the model is shown. Followed by an explanation of the gravity model which handles the trip distribution and mode choice of the model. Lastly, a remark is made on the traffic assignment technique that is used.

6.1.1. Model overview

The BBMA (Brabant Brede Model Aanpak) model is the transport model for the province of Noord-Brabant. The transport model is used to substantiate policy development for transport- and environmental-related issues. The model is used on a provincial scale but also on a smaller regional scale. This is

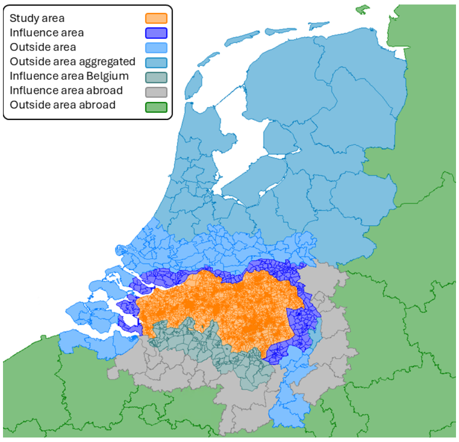


Figure 6.1: Part of the model area

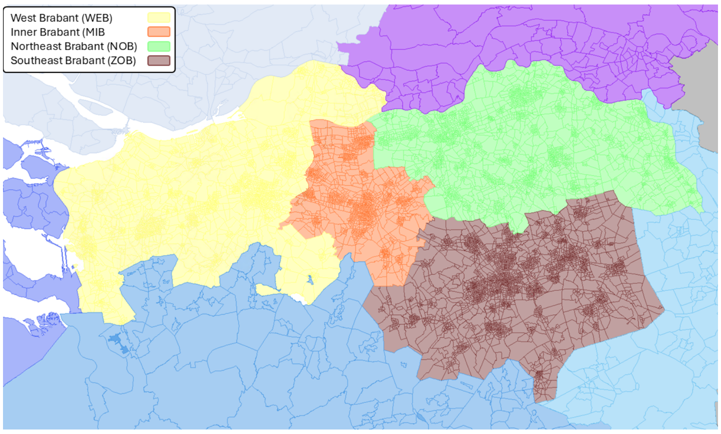


Figure 6.2: Sub-regions of the study area

done by estimating a model for the entire province of Noord-Brabant, which is later expanded into four regional models. The regional models facilitate a higher level of detail but the provincial base model guarantees that the input and methodology for the regional models is the same. This reduces errors between the four regional models and improves decision-making between the regions. The model is made and run in the OmniTrans software package, except for the trip generation model, which is calculated in Excel.

An overview of the study area with the surrounding areas of the provincial base model can be seen in figure 6.1. The model area also includes a large area of France and Germany, but these are not shown in the figure. The area types that are listed in the figure are also used in the model itself. Consequently, figure 6.2 shows the four regional models that lie in the study area. Note that the zonal distribution that is shown in the figures is on a regional scale level. The provincial model is estimated on 1425 zones, while in the figures, 12000+ zones are shown in the study area. This ensures that a city like Den Bosch can be modelled in detail in the regional model, but that it can also be compared on a coarser level for the entire province.

A transport model is made for a certain base year, for which all the input data for the model is gathered, such that the model can accurately predict the travel behaviour in that year. The model is also used to predict travel behaviour in future years, which is used to investigate what the impact is of a new neighbourhood on the current network. Different scenario's are used for the future years, which predict a low or high increase in car use as example. This information is taken from WLO scenario's.

Model categories
Table 6.1 shows the general characteristics of the standard workday model. The model uses five trip purposes, using the classification of ODiN trip purposes presented earlier in table 4.5. The next subsection will show what variables are used to predict the number of trips per purpose.

The model defines three modes of transport which are the Car, PT and Bicycle. For each mode of transport, a different network is created on which the traffic can be assigned. The car network is defined with multiple types of links, as a highway has a different capacity and speed than a provincial road. Next to this, the average parking cost per zone is defined in the car network, this variable is used later to calculate the generalised cost of travel. The cycling network is build up in a similar manner without parking costs. The public transport network is different and consists of transit lines for the Train, Bus, Tram or metro. Per transit line, the frequency or schedule of a public transit service is defined. The transit lines are connected by transit stop which can be reached by access and egress modes such as walking or cycling. To assure that the model correctly simulates the complexity of multimodal transport, a zenith assignment model is used. This assures that the most logical or fastest route is used between an origin-destination pair.

Next to trip purposes, car availability is a variable that is used to make classifications in the data that have different travel behaviour. Car availability is defined for persons who are older than 17 years old, who own one or multiple cars. A classification which has no car available is then more likely to take PT

Table 6.1: Classifications in a standard workday model and corresponding characteristics

Classifications	Characteristics
Trip purposes	Work, Business, Education, Shopping, Other
Modalities	Car, PT, Bicycle
Car availability	Yes/no
Urban density	Address density in 5 classes
Combination of classifications	Combination of characteristics
Trip purpose combination	Trip purpose and Car availability
Purpose-mode combination	Trip purpose, Car availability and Mode of transport

or the bicycle than a classifications of persons which has a car.

The last category that is used is that the zones are characterised on urban density based on the PC4 (Postal code level 4) address density in that zone. This is used within the model to reflect differences in trip generation for zones with different urban density, or in the modelling of public transport.

The model classifies these different characteristics into trip purpose combinations and purpose-mode combinations. These classifications are consequently used in the trip generation step and the parameter estimation of the model. As discussed in Section 3.3, making classifications in the model allows a modeller to classify different types of trips from the data, revealing differences in travel behaviour among the classifications. For example, a classification means that a combination is made with the trip purpose Work and No Car available. This is used to model travel behaviour that falls in this classification which might be different from other trip purpose combinations. Trip purpose combinations are sometimes also classified per trip production or trip attraction.

Model parameters

The model uses parameters to define the constant aspects of the model. Some parameters can be transferred between models as these remain relatively constant while others are used in the estimation of the model itself. Table 6.2 shows an overview of the parameters in the model that are relevant for this study.

Table 6.2: Parameters in a standard workday model

Parameters	Dimension
α, β for matrix estimation	Per trip purpose, mode, car availability class
Car occupancy rate	Per trip purpose
Policy parameters	Per year and scenario
Route factors	Per trip purpose and mode
Time of day factors	Per trip purpose combination

The α, β parameters are used in the matrix estimation process in the model, which will be further discussed in the subsection on trip distribution and mode choice. The car occupancy rate is used to convert the number of persons that take the car to a number of car vehicles. This better reflects the situation on the road, and this parameter differs depending on the purpose of the trip.

Policy parameters and route factors in the model are the Value Of Time (VOT), Value Of Distance (VOD) or the start cost of a trip. These parameters are used in the matrix estimation process and traffic assignment part of the model. A more detailed description of these parameters can be found in (Goudappel, 2024), as these parameters were not studied in this research.

Lastly, the time of day factors are used to split the obtained OD matrix into parts of the day. The matrix is first estimated for an average day but travel behaviour is not consistent over the day. Factors are then used to split the matrix into a morning peak, evening peak and the off-peak. This is done per trip purpose combination as the morning peak contains more people travelling to work than the evening peak.

6.1.2. Trip generation step

The trip generation model of the standard workday model is a zonal linear regression model which uses a single variable per trip purpose combination and the model uses scaling factors for the area type and the zonal density (Goudappel, 2024). The trip generation model uses equation 6.1 to calculate the number of trips arriving or leaving a zone per trip-purpose combination, or, in other words, the trip production and the trip attraction.

$$Y_{ik} = a_k X_{ik} \tag{6.1}$$

Defined by the following variables:

Y_{ik}	Total number of trips per zone i and area type k
a_k	correction factor per area type k
X_{ik}	input variable per zone i and area type k

The input variable can be the number of inhabitants or the number of jobs in a zone. An overview of the input variables that are used can be seen in table 6.3. As an example, the number of jobs in a zone is seen as a representative variable to calculate the number of work trips to a zone. As it is unknown how many work trips are made in the study area in total, this number is derived from the ODiN data per trip-purpose combination. The trip generation model then divides the total number of trips over the area in a linear way, based on the input variable, to acquire the number of trips per zone. The trip generation model is thus based on the assumption that differences between zones depend on differences in the input variable. The result of the trip generation model is thus a relative difference in trip generation between zones.

Subsequently, with the correction factors, the error term is minimised iteratively in such a way that the total number of trips from ODiN is approximately equal to the total number of trips in all the zones. As an example, zone A has 200 inhabitants and zone B has 250 inhabitants. The resulting trips leaving zone A are a 1000 trips, while 1200 trips leave zone B. On top of this, the factors per area type ensure that zones which both have 200 inhabitants but a different urban density differ in the number of trips arriving or leaving those zones.

Table 6.3: Variables used in workday trip generation model

Trip purpose combination	Production CA or CNA*	Attraction CA or CNA*
Home-Work	Working population	Jobs
Work-Home	Jobs	Working population
Home-Business	Working population	Jobs
Business-Home	Jobs	Working population
Business, not home	Jobs	Jobs
Home-Education	Inhabitants age 15-34	Students per school
Education-Home	Students per school	Inhabitants age 15-34
Home-Shopping	Inhabitants age 15+	Retail jobs
Shopping-Home	Retail jobs	Inhabitants age 15+
Home-Recreational	Inhabitants age 15+	Inhabitants
Recreational-Home	Inhabitants	Inhabitants age 15+
Other	Inhabitants	Inhabitants

**CA: Car available, CNA: Car not available*

Now that the calculation of the trip-generation model is explained, the variables and corresponding classification is exemplified from table 6.3. The model is estimated on 12 trip-purposes with four classifications, car available production, car available attraction, no car available production and no car available attraction. The classification in production and attraction is made to differentiate between trips originating in a zone or leaving a zone. The car availability classification is later used in the model to show differences in mode choice but to do that, the classification has to be incorporated in the trip generation step of the model. Each trip-purpose combination is based on different input data from ODiN, which is acquired with the same classification. The variable that is used per trip-purpose only differs for production and attraction, but not for car availability. Car availability thus only depends on the input data and is not a variable in the calculation itself.

To conclude, the trip generation model estimates 4 combinations per trip purpose. The variables that are used in the standard workday model are derived on data from the CBS or governments and this is applied to the zoning that is used in the model.

6.1.3. Trip distribution and mode choice

The result of a trip generation model is the number of trips that depart and arrive in a zone. The next step of the model is to link these trips between zones and to a mode of transport. In other words, the total number of trips leaving zone A is assigned a destination in zone B or C and so forth, with a mode of transport. This can be represented in an Origin-Destination (OD) matrix per mode. It's important to note that this is done in a synthetic model, which is a gravity model in this case. This means that the model is not directly based on observed trip patterns, but on generalised travel behaviour. This subsection explains relevant aspects for this thesis. For a more detailed description on this subject, the reader is referred to (Ortúzar & Willumsen, 2011).

The goal of the trip distribution and mode choice step is to obtain an OD matrix which shows the number of trips T_{ijpm} originating from zone i with destination j per trip purpose p and mode m. First of all, this result has to adhere to the constraints P_i and A_j set by the trip generation model, which is shown in Eq 6.2 and 6.3. In other words, P_i and A_j are the number of trips produced in zone i and the number of trips attracted to zone j.

$$\sum_j T_{ij} = P_i \tag{6.2}$$

$$\sum_i T_{ij} = A_j \tag{6.3}$$

The distribution of trips between the zones is not distributed arbitrarily but this is based on the generalised cost to travel c_{ij}. The generalised cost is a function of the resistance to travel. Variables included in the cost can be the initial cost, travel cost, parking cost or the VoT. In this way, multiple costs of travel are included to represent the resistance to travel instead of only the distance. As the resistance to travel is not linear over the distance, a distribution function or deterrence function is used to express how this scales over the distance. A distribution function can highlight that the resistance to travel between a trip of 2 km and 3 km is small, but that this difference is larger between a trip of 3 km or 10 km. Therefore, the distribution of trips follows a distribution or deterrence function which can have several shapes, a log-normal deterrence function is shown in equation 6.4 and examples of the shape of a distribution function are given in figure 6.3.

$$F_{pm}(c_{ijpm}) = \alpha_{pm} * exp^{(-\beta_{pm} * ln^2(c_{ijpm}+1))} \tag{6.4}$$

Defined by the following variables:

F_{pm}	distribution function for purpose p and mode m
α_{pm}	parameter for purpose p and mode m
β_{pm}	parameter for purpose p and mode m
c_{ijpm}	Generalised cost from zone i to zone j for purpose p and mode m

α and β are the parameters that influence the shape of the distribution function, where α governs the height of the distribution function and β indicates the slope of the distribution function. The distribution function is then used in equation 6.5 which calculates the desired OD-matrices. The effect of the deterrence function is that if the cost to travel is large between zones, a small number of trips is assigned on that OD-pair. In this way, the distribution of trips between OD-pairs, follows the pattern of the distribution function.

$$T_{ijpm} = \frac{a_i P_{i,p} b_j A_{j,p}}{F_{pm}(c_{ijpm})} \tag{6.5}$$

Defined by the following variables:

T_{ijpm}	The number of trips from zone i to zone j per purpose p and mode m
$P_{i,p}$	Number of produced trips in zone i per purpose p
$A_{j,p}$	Number of attracted trips in zone j per purpose p
a_i, b_j	Scaling factors for production and attraction
$F_{pm}(c_{ijpm})$	Deterrence function based on the generalised cost from zone i to zone j for purpose p and mode m

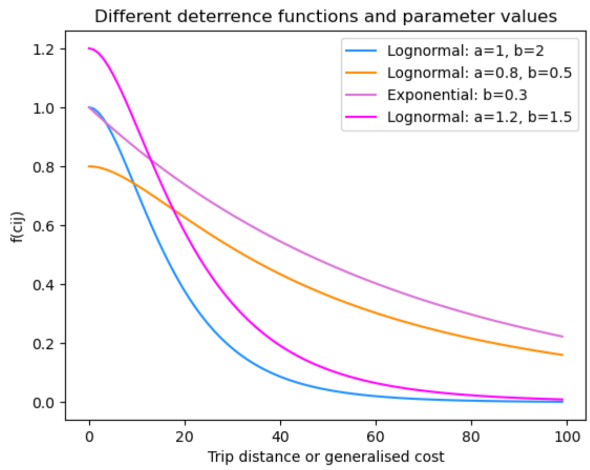


Figure 6.3: Examples of different deterrence functions and parameter values

Not only does the deterrence function influence the gravity equation that is shown in Eq 6.5 but it also has to adhere to the constraints that are set in the model. Two constraints were already mentioned and shown in Eq 6.2 and 6.3, but the model uses two other constraints. Firstly, in some zones, parking constraints are set to limit the trips to a zone. This simulates the available parking space in city centres. Secondly, constraints are set per trip length distance class, based on the ODiN data. This assures that the trip distribution model follows trip length distributions that were observed in the data, on top of the shape of the deterrence function. This poses a challenge in the estimation of the α, β parameters as the deterrence function has to adhere to multiple constraints.

The resulting problem is solved as a multi-level optimization problem, as the solution has to adhere to multiple constraints and there can be many possible solutions. The algorithm behind this approach is not explained in this research in detail. A more detailed description can be found in (Pots, 2018). For this research, it is important to highlight that the parameters have to be estimated once for the model. Regular changes in the model do not require new parameters but only a re-estimation of the OD-matrices. The final result of this step is then an Origin-Destination (OD) matrice per purpose and mode.

6.1.4. Traffic assignment

The generated OD-matrices can then be assigned to the subsequent transport networks per mode. In this research, an All-Or-Nothing (AON) assignment method was chosen for shorter computation times. The method is based on the idea that all traffic chooses the fastest route, regardless of the capacity of that route. Normally, more advanced assignment methods are used in the standard workday model to incorporate network capacity constraints.

6.2. Model adaptations

This section is structured in the following way, first the information from all the chapters is substantiated. Then the adaptations are described in a technical way per model version.

6.2.1. Review of model adaptations

The introduction of this chapter highlights the broad analysis that is done to try and think about how a workday model can be adapted into a Saturday model. This subsection will substantiate the choices that were made to develop a preliminary Saturday model by first discussing how the information from Chapter 2, 3, 4 and 5, is used to make these decisions.

Table 6.4: Overview of characteristic differences in work- an weekend day travel, with the corresponding adaptation and effort/benefit from Chapter 3

	Characteristics	Adaptation	Effort - Benefit
C1*	Different trip purposes have a higher share in the weekend.	Use different trip purposes in a weekend day model	Medium - High
C2*	Saturdays and Sundays show different travel behaviour	Model Saturday and Sunday separately	Low - High
C3	There is more difference in activity patterns between persons.	Incorporate different variables or classifications to show differences in travel behaviour in the model	High - Medium
C4	The weekend has different constraints/obligations and therefore a higher temporal variability.	Model different time periods or show the possible bandwidth of the results	Low - Low
C5	Spatial variability of travel is higher, people tend to explore new activities/destinations.	Incorporate the possible destinations per trip purpose in the trip generation or trip distribution step of the model.	Medium - High
C6	Larger difference in trip-chaining behaviour between people	Consider a tour-based model, if this is required.	-
C7	The choice for an activity is more important than the choice for a mode of transport.	Asses whether the model structure is sufficient to model the dependency between activity choice, destination choice, mode choice and route choice in the model.	High - Low
C8	There is more joint travel in the weekend, especially within a household	Include variables that reflect joint travel or update the attribute in the model.	Low - Low
C9	Mode choice is different	Re-estimate mode choice parameters	Medium - High
C10	Time of day of travel is different	Model different time-periods.	Low - Low
C11	The value of travel time is different	Re-estimate the VOT and other required attributes for a weekend day model.	Medium - Low
C12	External effects like road works, events or seasonal variations can all have a different effect on the choice to travel in the weekend as there are less constraints to travel.	Consider a certain bandwidth in the models results or a standard set of variants which reflect these external factors.	Medium - Low

**necessary adaptation for a Saturday model*

First of all, Chapter 5 has concluded that the development of a preliminary Saturday model will help to answer the question what the possible purpose can be of a Saturday model. This was not directly clear from the interviews, as before it is known if a model can help in policy development, it is important to develop such a model itself. Next to this, a set of use cases were identified which justify the development of a preliminary Saturday model, as these use cases require a basic Saturday model. Lastly, the Chapter concluded that both the four-step modelling paradigm or an activity based model could be used to model a Saturday. This confirms that the BBMA model can be used to create a Saturday model, as this was a choice that was made earlier in the research.

Secondly, Chapter 2 and 4 have shown that travel on weekend days is different from workdays. This was summarized in a set of differences and recommendations, where the differences were later used in Chapter 3 to create a set of adaptations and the recommendations will return in the conclusion of this research. These were not directly applicable as an adaptation to the model. Chapter 3 furthermore contributes to this analysis by providing background theory on modelling approaches and the four-step model. The most important part of this chapter was the analysis of how the differences in travel behaviour between work- and weekend days, could be used to adapt a workday model into a Saturday model. Subsequently, the adaptations were ranked on their required effort to implement the adaptation in the model and the perceived benefit of the adaptation in it's ability to model Saturday travel behaviour. Additionally, two adaptations were found to be necessary to create a Saturday model. An overview of the differences in travel behaviour and the corresponding adaptations with their effort/benefit is shown in table 6.4.

Now that this research has made an overview on the effort and the benefit of an adaptation. A choice should be made on which adaptation is implemented in the Saturday model, as it is a better approach to adapt a model in steps, then to try and implement all the adaptations at the same time. That would make it unclear what the impact is of an adaptation on the model and the result of the adaptation can not be validated separately. Table 6.4 highlights that adaptation C1 and C2 are necessary adaptations to create a Saturday model. Without these adaptations, there is not really a difference with the workday model. Next to this, both model adaptations bring a high benefit and the required effort is medium or low. Therefore these adaptations are chosen for the first Saturday model version.

In addition to this, adaptation C9 is chosen as well. When a transport model is created, or adapted for a different year, a number of steps have to be taken to make the model. One of these steps is the estimation of mode choice in the model area. The model development in this research will thus have to follow the same steps which are normally taken to make a model and this thus includes the estimation of mode choice. Therefore, adaptation C9 is included in the first Saturday model version. Although this is a more trivial decision as this is a part of the development of a model, it's good to highlight that mode choice is an important difference of Saturday travel and that it should be included in the model.

Based on the list of adaptations, more adaptations can be implemented too increase the realism or functionality of the model. The only remaining adaptation which has a high benefit is adaptation C5, and after that adaptation C3 is the only adaptation which has a medium benefit. The rest of the adaptations have a low benefit, but the required effort is also low for some adaptations. This makes it difficult to directly choose what the next adaptation should be, therefore this choice is also based on the technical implementation of the first Saturday model version. In this way, it can be checked which assumptions are made and if these can be improved by a certain adaptation. To conclude this subsection, adaptation C1, C2, and C9 are chosen for the first Saturday model version and this will be described technically in the next subsection.

6.2.2. Saturday model A

Saturday model A is the first version of the Saturday model that is made in this research, based on adaptations C1, C2 and C9. The main change with the workday model is the use of different trip purposes in the model and parameters are estimated for the model, based on Saturday travel data from ODiN. Next to this, attributes in the model that correspond to a trip purpose were changed to reflect the Saturday trip purposes. This subsection will first describe the changes that were made to the trip generation component of the model, to show which variables were chosen to predict the Saturday trip purposes. Secondly, a description is given of parameters that were changed in the model. ODiN data from the years: 2018, 2019, 2022 and 2023 were used as an input to the model. The data was filtered to only include Saturdays and subsequent national holidays, such as Easter, were also filtered from the data if this was on a Saturday.

Trip generation model

In Chapter 4, an analysis was done into a possible Saturday trip purpose distribution. As shown in section 6.1, the trip-generation model uses 12 trip-purpose combinations. The Saturday trip purposes would thus have to fit in 12 combinations. Therefore, the first five trip purposes were included in both directions, while 'Pick up/drop off' and 'Other' were included in one direction in the model, shown in table 6.5. After that, the explanatory variables had to be chosen for the Saturday trip purposes.

Table 6.5: Adapted trip purpose pairs and explanatory variables for Saturday model A

Trip purpose combination	Production CA or CNA*	Attraction CA or CNA*
Home-Work	Working population	Jobs
Work-Home	Jobs	Working population
Home-Shopping	Inhabitants age 15+	Retail jobs
Shopping-Home	Retail jobs	Inhabitants age 15+
Home-Socrec	Inhabitants age 15+	Inhabitants
Socrec-Home	Inhabitants	Inhabitants age 15+
Home-Sport	Inhabitants age 15+	Inhabitants
Sport-Home	Inhabitants	Inhabitants age 15+
Home-Visit	Inhabitants age 15+	Inhabitants
Visit-Home	Inhabitants	Inhabitants age 15+
Pick up/drop off	Inhabitants	Inhabitants
Other	Inhabitants	Inhabitants

**CA: Car available, CNA: Car not available*

For the trip purposes 'Work', 'Shopping' and 'Other', the variable was kept from the workday model, as 'Work' and 'Shopping' already had a separate variable and because 'Other' is not really definable. For the trip purposes 'Socrec', 'Sport' and 'Visits', a new variable was required. An earlier analysis of the literature in section 3.4 showed that it is not clear from the literature which variables should be used for these trip purposes in a regression model with a single variable. It did show that socio-demographics variables have better explanatory power in trip production and that variables used in trip attraction are not as detailed. From the socio-demographic variables it is likely that the number of inhabitants in a zone can best showcase the differences between zones. Therefore this variable is chosen for the trip generation but also for the trip attraction, as there are no clear variables which can predict trip purposes like Socrec, Sport and Visits for trip attraction. This will mean that the destinations of these trip purposes will not match correctly, but it allows for a first test of how a Saturday model works with these trip purposes.

Model parameters

Apart from the trip generation model, parameters in the model were changed to correspond to the new trip purposes and the Saturday travel data. In section 6.1 an overview was presented of the model parameters in table 6.2. Only the α, β parameters were estimated for the first Saturday model version, while the other parameters, such as the car occupancy rate, were changed, based on the previous workday attributes. This is illustrated in table 6.6.

Table 6.6: Attribute change per trip purpose

Saturday trip purposes		Attribute from reference trip purpose
Work	$\leftarrow$	Work
Shopping	$\leftarrow$	Shopping
Soc-Rec	$\leftarrow$	Other
Sport	$\leftarrow$	Other
Visits	$\leftarrow$	Other
Pick upp/drop off	$\leftarrow$	Other
Other	$\leftarrow$	Other

6.2.3. Saturday model B

A second Saturday model was created so that the results could be compared with Saturday model A, and to include more realism or functionality in the model. Adaptation C5 is implemented in this model version for two reasons. Firstly, the trip attraction variables of Saturday model A can't realistically portray the destinations that belong to these trip purposes. Secondly, it was a wish from the company to explore, the use of different variables for non-work trip purposes. This made the choice for adaptation

C5 trivial, as this describes that a Saturday model should include the different destinations that belong to Saturday travel. Furthermore, the literature review in section 3.4 showed that trip attraction can be improved by using detailed spatial data. In one of the papers, Open StreetMap (OSM) data was identified as a data source for such a model (Klinkhardt et al., 2021). This was used as an inspiration for adaptation C5, instead of OSM data, data from the land registry was used which is referred to as BAG data in this research. An analysis was performed on this data which resulted in variables that could be used for three of the trip purposes in the model. This subsection shortly summarises the analysis that was performed on the BAG-data, and the changes to the model are mentioned.

Appendix B describes the analysis of the BAG-data in detail. BAG-data consists of the address registration of all the buildings in the Netherlands, each address has a building use which is defined in the BAG-data. 11 Building are defined in the BAG, which can be industrial, shopping, living or educational. The appendix then further describes if a building use can match to a specific trip purpose and an analysis is made of the data per building use. Relevant building uses were then chosen for three trip purposes and the BAG-data was summed per zone to retrieve a variable which could be used in the trip generation model. The variable was then subjected to a check and this showed that one of the building uses could not be used. The result of the BAG-data analysis is that the trip purposes Shopping, Socrec and Sport can be predicted by a variable created with the BAG-data. These are the surface area of shops per zone, the surface area of social-recreational buildings per zone and the surface area of sport buildings per zone. Furthermore, the analysis showed that the current variable used to predict trip attraction of shopping trips can be changed to the variable from the BAG-data. A last note should be made on the quality of the BAG-data. The data was not subjected to an extensive filtering process, as this research was interested in how the variables would perform in the model itself.

The resulting changes to the trip generation model can then be seen in table 6.7. The variables for the trip generation were kept the same as it is assumed that the number of inhabitants can correctly portray the relative differences between zones. Consequently, this allows for a better comparison with the previous model version.

Table 6.7: Adapted Trip purpose pairs and explanatory variables for Saturday model B

Trip purpose combination	Production CA or CNA*	Attraction CA or CNA*
Home-Shopping	Inhabitants age 15+	*Surface area shops*
Shopping-Home	Surface area shops	Inhabitants age 15+
Home-Recreational	Inhabitants age 15+	Surface area SocRec
Recreational-Home	Surface area SocRec	Inhabitants age 15+
Home-Sport	Inhabitants age 15+	Surface area Sport
Sport-Home	Surface area Sport	Inhabitants age 15+

**CA: Car available, CNA: Car not available*

Other than the trip generation model, no changes were made in Saturday model B. Changes in the trip generation component have no effect on input data from ODiN, the same input data is used in for example the parameter estimation of the model, so the parameters that were estimated for Saturday model A were also used in Saturday model B.

6.2.4. Workday reference model O

As a reference model O, the standard model setup for a workday was used for the BBMA model as was described in section 6.1. This model version is used to compare the performance of other model versions in this research. The model is estimated with ODiN data from the years 2018, 2019, 2022 and 2023, which is then filtered to only include workdays.

6.2.5. Model versions

The described adaptations result in three model versions where the Saturday model has two versions and there is a reference model. Table 6.8 shows the adaptations that were implemented in each model version and which days of the ODiN data were used to create the development. All three model versions are based on the model setup of the BBMA model which is described in section 6.1. The changes for each model version were made in the OmniTrans software package, except for the trip generation model which is made in Excel. Changes were thus made to properties and parameters of the model and scripts that execute the model had to be changed to reflect the different model properties or input data.

Table 6.8: Model versions in this research

Model versions	ODiN Data		Adaptations
Workday model O	Workday data	-	-
Saturday model A	Saturday data	C1, C2, C9	Saturday trip purposes in trip generation model and estimation of model parameters.
Saturday model B	Saturday data	C5	Different variables in trip generation model for higher spatial detail.

6.3. Model outcomes

To be able to compare the model, the following hypothesis are constructed to test the outcomes of the model.

6.3.1. Parameter estimation

Estimation of the α, β parameters is an important aspect of model development as the α, β parameters govern the trip distribution and mode choice in the model. Parameters had to be estimated for Workday model O and Saturday model A. Saturday model B uses the same parameters from Saturday model A, as these are based on the same input data from ODiN.

Description of the estimation

The parameters are estimated within the OmniTrans software package based on the methodology presented in section 6.1. Parameters are estimated per purpose-mode combination, so for the purpose: Work Car Available or Work No Car Available, α, β parameters are estimated for the modes: Car, Public transport (PT) and Bicycle. This means that six combinations are estimated per trip purpose. The required input for the estimation are the constraints set by the model and input from the ODiN data per purpose-mode combination. These are the average trip length and the total number of trips per trip length distance bin, e.g. the trip length distribution.

At the start of the calculation, start values are used, which are $\alpha = 1$ and $\beta = -0.5$, this prevents that the calculation converges to a local optimum, based on previous parameters. The parameters are changed stepwise in the multi-level optimization algorithm, based on the gap to the optimal solution. This is done for 50 iterations, after which the estimation process ends. The result of this is the α, β parameters and a trip length distribution of the trips in the model.

Comparison of results

The α parameter influences the height of the deterrence function and thereby influences the choice for a mode of transport. The α parameter within a purpose-mode combination is meant to influence the modal split in that purpose. The β parameter influences the slope of the deterrence function or the choice for a long or short trip. This is thus the parameter that influences the trip length distribution. As a reference, the parameters from the previous workday model that is based on OViN data is included in Appendix D. This shows how the α parameters mainly influences the modal split per purpose as the α parameter for public transport (PT) is close to 1 for most purposes while the other values are larger. This indicates the low share of PT in the modal split. Furthermore, a β parameter close to zero indicates that more long trips are made, while a β parameter close to -1 indicates that more short trips are made. This difference is reflected in the $\beta's$ of the purposes Work and Shopping.

The shape of the deterrence function is not directly comparable to the obtained trip length distribution. The trip length distribution that is an input to the model is compared to the trip length distribution calculated in the model, next to an analysis on the obtained parameters. Differences in the two trip length distributions are then analysed per purpose-mode combination with a correlation coefficient and the difference of the Root Mean Square Error (RMSE). The correlation coefficient can indicate whether the two distributions are alike and the difference in RMSE can show how the overall error has increased or lowered between the trip length distributions.

Next to this analysis, it was found during the parameter estimation process that the obtained trip length distributions contained an error in the low distance bins. Per model version, a new subversion was created with different trip length bins, to analyse if this solved the error and which subversion of the model should be used. This resulted in the subversions shown in table 6.9.

Table 6.9: Model subversions in the parameter estimation

	Model subversions	Changes compared to previous subversion
O1	Workday model	
O2	Workday model	Trip distribution distance bins
A1	Saturday model version A	
A2	Saturday model version A	Trip distribution distance bins
B2*	Saturday model version B	

Not included in the comparison as the parameters are similar to model A

6.3.2. Internal goodness-of-fit of the model

The performance of the model versions is compared with the ODiN data that is used to create the model. This is therefore an internal goodness-of-fit measure, as the model is compared with its own data source. This is done for the trip purpose distribution, the modal split and the trip length distribution, as described below. These are all compared in a relative way by looking at the percentages. These measures are used by the company to check how a model performs and serve as a test to check how the model handles the input data. Large differences in the outcome of the model can show that there is an error and it allows for a comparison with the workday model. Next to the internal validation of the model, an external validation is presented with NVP data, which is described in section 6.4. The outcomes of the model are compared with NVP data to investigate what differences there are and to check how the model portrays travel behaviour.

- Trip purpose distribution should fall within a 5 % range of the ODiN data.
- Modal split per trip purpose should fall within a 5 % range of the ODiN data.
- Trip length distribution per trip purpose should fall within a 5 % range of the ODiN data.

6.3.3. Travel demand analysis

As it is expected that the model functions well for the entire region, this analysis focuses on how the model differentiates in travel behaviour on a smaller scale level. Results of the model versions are compared on a municipal and local level. The municipalities that were selected for this analysis can be seen in figure 6.4. These are the municipality of Heusden, 's-Hertogenbosch and Oss, these were chosen as they differ in size and characteristics. For the local scale level, three neighbourhoods were selected within the municipality of Den Bosch. The neighbourhoods consists of multiple zones in the model and these can be seen in figure 6.5. The city centre of Den Bosch was chosen as it contains a high number of shopping and social-recreational destinations. A regular neighbourhood was chosen as a reference zone, and lastly, an industrial area in Den Bosch was chosen as it contains department stores. Next to this, these zones contained the highest number of observations in the NVP data when compared to other neighbourhoods. This increases the chances that a valid comparison can be made.

In this analysis, each area will be analysed on the trips that are arriving in that area, or in other words, the model will be analysed on the trip attraction side. This allows for an analysis on the places people travel to on Saturday to investigate how the model portrays travel behaviour. Subsequently, the model results are also compared with the NVP data. By focusing on trip attraction, trip production and intrazonal trips are not analysed. Trip production and trip attraction are relatively constant in the model so leaving trip production out has no effect on the analysis but the intrazonal trips say something about the travel within a zone. As a larger zone or a municipality is analysed, more intrazonal trips are not regarded in the analysis and this changes the results.

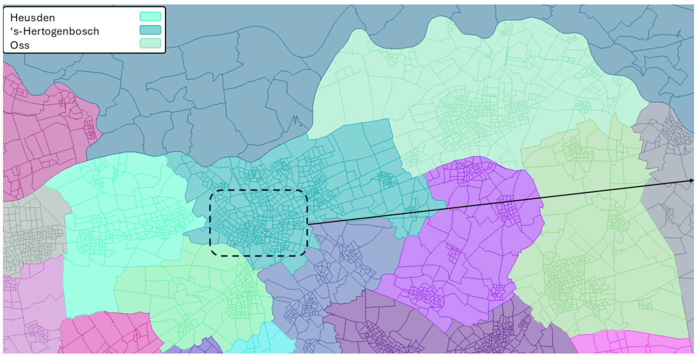


Figure 6.4: Analysed municipalities

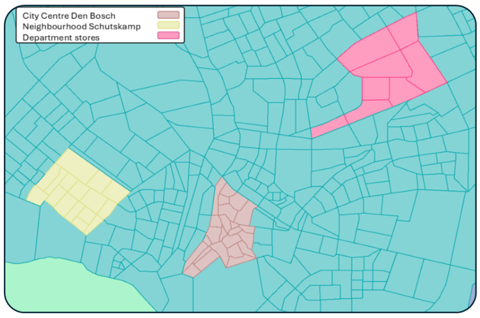


Figure 6.5: Analysed zones in Den Bosch

The results were obtained via the OmniTrans software with a matrix compress operation. This is an operation were the origin-destination matrices of all the zones is compressed into the required scale level. This is achieved by defining to what municipality or neighbourhood a zone belongs. The results were split per trip purpose and mode of transport so that these could be analysed in this section. The NVP data was processed to make the data comparable to the model results. This was done by checking if the area's were defined in a similar way and by removing the intrazonal trips from the data. The NVP data is retrieved as unweighted data so the model results and NVP data will be compared on the share per trip purpose or modal split instead of on the total number of trips. Furthermore, it is not possible to analyse the trip length distribution per area with this method as the origin-destination matrix only has information on the number of trips that were made.

6.4. Validation steps

This section will describe the validation steps that were taken to validate the model. First, the validation of the input data for the model is discussed. This is done because the results of the model directly relate to the input data and it's difficult to validate sub-steps of the model. Secondly the external dataset is described which is used to validate the general outcomes of the model and the travel demand at local levels. The terms trip-purpose combination and purpose-mode combination are often used in this section. For a detailed description of these terms, the reader is referred to section 6.1. Additionally, when a remark is made such as: 'All Car purpose-mode combinations'. A reference is made to all purposes which contain the mode Car.

6.4.1. Input data validation

There are two ways in which the ODiN data is used as input data for the model. This is in the trip generation model and in the parameter estimation. First, the validity of the input data for the trip generation model is described. Secondly, the method to determine the validity of the trip length distributions per purpose-mode combination that are used as an input for the α, β parameter estimation are described. After that, the results of this will be shown and it will be explained what this means for the results of the model.

The input data for the trip generation model is obtained from ODiN by calculating the total number of trips that are made in the study area per trip-purpose combination. This is done for the workday and Saturday model. the total number of trips per trip-purpose combination was based on a minimum of 170 observations or more. As an example, the trip-purpose combination 'Home-Work/Car available/Production', has a total number of 104.327 trips in the study area, which is based on 186 observations. The large number of observations guarantees that the input data is valid.

In the parameter estimation, trip length distributions are used per purpose-mode combination as an input from ODiN data. A trip length distribution is divided in a set of distance bins and instead of looking at the total number of observations. The validity of the data is assessed by looking at all distance bins. In general, more short trips are made than long trips, so there is more data in the distance bins with short trip lengths. In a distance bin with long trip lengths, there can be a few observations but this doesn't mean that this distance bin is invalid with respect to the rest of the distribution. Especially for a bicycle trip length distribution, there can be distance bins with zero trips but this doesn't affect the validity of the entire trip length distribution. Therefore, the validity per distance bin is calculated and this is combined into a single measure. This is done with equation 6.6, which calculates the confidence interval per distance bin, by using the fraction $\hat{p_i}$ of observations per distance bin. Proportional to the total number of observations N in the trip length distribution.

$$p_i = \hat{p_i} \pm z_{\alpha/2} * \sqrt{\frac{\hat{p_i}(1-\hat{p_i})}{N}} \tag{6.6}$$

This results in the confidence interval per distance bin p_i in each purpose-mode combination for a 95 % confidence interval, denoted by $z_{\alpha/2}$ for a nominal distribution. From this, the confidence interval per purpose-mode combination is calculated by taking the average of p_i to obtain the width of the confidence interval CI. A wider confidence interval then indicates that the input data is less accurate. As a rule of thumb, a purpose-mode combination with a width below 5 % is deemed as valid input data for the model. A width which is between 5 % and 10 % is deemed as questionable input to the model which needs to be verified and a width which is larger than 10 % is not seen as valid input data to the model.

As the input data for the parameter estimation is given per purpose-mode combination, the parameter estimation also has input on the modal split per purpose. The validity of the modal split can also be checked by investigating the validity of a purpose-mode combination. Therefore, the validity of the modal split is not checked separately. Lastly, the input data for the different subversions of the model didn't give any different results in terms of data validity. The only difference is in the distance bins with short trips, and these are not problematic for the validation. Therefore, this is not shown per model-subversion in this section.

Workday model
Table 6.10 shows the width of the confidence interval per purpose-mode combination for the workday model O2. Most of the car and bicycle purpose-mode combinations have a small confidence interval. This means that it is likely that the trip length distribution follows a logical distribution without any big gaps. Consequently, this means that the distribution is based on a sufficient number of observations and that it can be seen as a valid input for the model. Purpose-mode combinations, such as most of the Public Transport (PT) purpose-mode combinations, show a different result, as some purpose-mode combinations have a confidence interval larger than 5% or 10 %. This can mean that there is too little data at all, or that there are too many distance bins with insufficient data, resulting in a high average error. For some combinations it's logical that there is too little data. For example, in the 'Education Car Available' combination, the definition of car availability is based on age. As a result, almost no trips fall under this classification, but in the 'Car Not Available' classification.

Table 6.10: Width of confidence interval (CI) per purpose-mode combinations based on ODiN workday data

Workday	Car	PT	Bicycle
Work CA	0,01	0,05	0,01
Work CNA	0,02	0,03	0,01
Business CA	0,02	0,13**	0,06*
Business CNA	0,03	0,13**	0,05
Education CA	0,05	0,15**	0,12**
Education CNA	0,02	0,03	0,01
Shopping CA	0,01	0,35**	0,01
Shopping CNA	0,01	0,12**	0,01
Other CA	0,01	0,06*	0,01
Other CNA	0,01	0,03	0,01

**CI > 5%, **CI > 10%*

Saturday model
The same method is applied to the input data for the Saturday model and the results can be seen in table

6.11. The results are comparable to those of the Workday model but all PT and more bicycle purpose-mode combinations have a large confidence interval. One explanation for this is that the modal split of these modes is lower in the weekend and as a result, little data is available. Next to this, the distinction in Car Availability causes a further reduction in available data per purpose-mode combination. When the Car purpose-mode combinations are compared, it can be seen that the confidence interval is larger than for a Workday model but this stays within the 5 % range.

Table 6.11: Width of confidence interval (CI) per purpose-mode combinations based on ODiN Saturday data

Saturday	Car	PT	Bicycle
Work CA	0,04	...**	0,09*
Work CNA	0,06*	0,25**	0,04
Shopping CA	0,02	...**	0,02
Shopping CNA	0,02	0,38**	0,02
Socrec CA	0,04	0,28**	0,08*
Socrec CNA	0,04	0,13**	0,06*
Sport CA	0,04	...**	0,06*
Sport CNA	0,04	0,79**	0,03
Visits CA	0,03	0,77**	0,06*
Visits CNA	0,04	0,13**	0,04
Drop off/pick up CA	0,04	...**	0,17**
Drop off/pick up CNA	0,05	...**	0,12**
Other CA	0,03	0,36**	0,06*
Other CNA	0,03	0,11**	0,04

**CI > 5%, **CI > 10%*

What does this validation step mean for the results of the model? First of all, it shows that the higher data availability for a Workday, delivers more purpose-mode combinations with a small confidence interval. Despite this, not every purpose-mode combination for a Workday has a small confidence interval, meaning that the workday model also suffers from limitations in data availability. Secondly, it is likely that a purpose-mode combination with a small confidence interval has a logical trip length distribution. This increases the chance that parameters can be estimated which correctly show the trip length distribution in the model. In the case of a large confidence interval, the trip length distribution can have gaps or some distance bins are under represented due to limited data. This makes it hard for the model to correctly estimate parameters as the input data is not a correct portrayal of the real trip length distribution. This observation is important for the analysis of the results, as the error leads back to the input data, making an analysis of these results unnecessary.

6.4.2. Validation data: NVP

Data from the 'Nederlands VerplaatsingsPanel' (NVP) was used as an external data source to validate the outcome of the model. The NVP uses GPS to track respondents and infers characteristics of trips from this data. Respondents are tracked for a longer period of time, which makes the data suitable for longitudinal studies. The NVP data was not used in the estimation of the model as the respondents in the ODiN data better represent the Dutch population and there are more respondents in ODiN. This delivers a more varied view of travel behaviour in the Netherlands but the NVP data is still suited to develop transport models.

The NVP data is used in this research to validate the results of the model. This is done on the general results of the model and local scale levels, as described in section 6.3. The goal of this comparison is to investigate if there are large differences between the outcome of the model, which is based on ODiN data, by comparing it with different data on travel behaviour. A distinction should be made in this comparison between systematic errors and random errors between the two datasets. Systematic errors can stem from differences in survey setup, as ODiN is based on reported trips from the respondents and NVP depends on the automatic classification of GPS data. While the GPS-based approach is prone to errors in the classification, respondents make mistakes or forget things while reporting their trips, so there is no faultless approach (Los et al., 2024). Random errors occur in the data because a different number of respondents is used which make different choices to travel. This thus showcases the variation within the data but for this comparison, it's more important to know what kind of systematic errors occur.

Los et al., 2024 reported on these differences by comparing two panel datasets with a different survey setup. The GPS-based survey was found to report a higher number of trips, as people forget to report on some trips. The modal split was found to be comparable but the trip purposes showed more differences and the classification method of the NVP could be improved in this.

7

Model Results

In this chapter, the results of the model versions will be described. This allows for an evaluation of the adaptations that were made, and to consider how a Saturday model performs in general with the model setup that was used. The model adaptations themselves and why these adaptations are made are described in the previous chapter.

How does the developed model perform when compared to travel data on a Saturday?

This chapter is structured in the following way, the section 7.1 describes the results for the estimated parameters for both the Workday and Saturday model and it explains which subversion is chosen for further analysis. After that, the internal goodness-of-fit measures of the model are shown for the Saturday and Workday model in section 7.2. Following on that, section 7.3 performs a detailed travel demand analysis by analysing the trip purpose distribution and modal split of municipalities and neighbourhoods in the study area. Lastly, a conclusion describes the key takeaways of this Chapter.

The terms trip-purpose combination and purpose-mode combination are often used in this Chapter. For a detailed description of these terms, the reader is referred to section 6.1. When a remark is made such as: 'All Car purpose-mode combinations'. A reference is made to all purposes which contain the mode Car. Other than that, when a reference is made to a mode of transport in general, this is confined to the modes that are present in the model which are the Car, Public Transport (PT) and the Bicycle.

7.1. Parameter estimation

New α and β parameters were estimated for both the workday and the Saturday model. The α, β parameters govern the shape of the deterrence function which is a portrayal of the resistance to travel. As was shown in Section 6.4, only the parameters for the Car purpose-mode combinations are likely to deliver valid results. Therefore, the parameters for the PT and bicycle purpose-mode combinations are not shown in this section but in appendix D. This appendix shows that the PT purpose-mode combinations showed little correlation between the model and the input data. Indicating that the trip length distribution in the model is not realistic. Secondly, this appendix shows that there is not much difference between the model versions in the results for the bicycle purpose-mode combinations and that the model can thus correctly estimate the parameters for the bicycle combinations.

After the obtained parameters are compared, the obtained trip length distributions are compared with the trip length distributions from ODiN data. Based on these results, a decision is made to use subversion A1 or A2 of the model.

7.1.1. Saturday model A parameters

The obtained α and β parameters are shown in table 7.1 for model subversions A1 and A2. It can be seen that the α parameters are different for model A2 but the order of magnitude is the same. This is because the α parameter reflects the mode choice and therefore there should be no large differences. Additionally, the change in parameters can stem from a different local optimum that was found in the calculation. Nevertheless, in comparison with the expected parameters from the previous workday model, which can be seen in appendix D. The α parameters are much higher for the car and bicycle purpose-mode combinations while the PT combinations remain unchanged from the start-value. The β parameters have become closer to -1. This can be explained by the fact that the number of trips in the short distance bins have shifted. The β parameter reflects this, as this means that it's more likely that people make short trips than long trips. The trip purpose Shopping and Pick up/Drop off do thus have the largest share of short trips, as the β is closest to -1. Alternatively, the trip purposes Visits and Socrec have the largest share of long trips.

Next to that, the correlation coefficient is shown for both model subversions and the difference in RMSE is shown in percentages for the trip-purposes in table 7.1. 11 out of 14 trip purposes show a higher correlation coefficient for model A2 than for model A1 and this is accompanied with a lower RMSE value. A slight change in the correlation coefficient can thus mean a large change in the RMSE of the trip length distribution. Alternatively the 'Work CA' purpose shows that a lower correlation coefficient can come with a lower RMSE. This can mean that the distribution in model A1 better followed the distribution of the original data than model A2 but that the squared errors between the values is smaller for model A2.

Table 7.1: α, β parameters and statistics for mode Car in Saturday model A

Purpose	α_{A1}	α_{A2}	β_{A1}	β_{A2}	Cor A1	Cor A2	Diff RMSE (%)
Work CA	70,95	378,59	-0,401	-0,430	0,608	0,602	-2,9
Work CNA	3,97	2,49	-0,375	-0,417	0,745	0,547	3,0
Shopping CA	3827,19	2764,19	-0,542	-0,622	0,930	0,998	-58,5
Shopping CNA	251,94	161,39	-0,510	-0,594	0,878	0,978	-32,8
SocRec CA	24,34	20,12	-0,366	-0,373	0,353	0,894	-47,8
SocRec CNA	33,31	33,82	-0,359	-0,374	0,574	0,733	-16,4
Sport CA	119,14	114,21	-0,401	-0,412	0,642	0,923	-38,4
Sport CNA	33,58	24,45	-0,387	-0,406	0,895	0,981	-40,1
Visits CA	13838,90	15258,94	-0,350	-0,344	0,597	0,606	-4,8
Visits CNA	387,57	348,57	-0,326	-0,314	0,744	0,511	12,7
Pick up/drop off CA	250,11	137,85	-0,447	-0,463	0,890	0,950	-11,9
Pick up/drop off CNA	1440,99	1252,33	-0,483	-0,515	0,928	0,964	-11,8
Other CA	465,21	300,86	-0,397	-0,406	0,904	0,943	-9,1
Other CNA	131,44	158,53	-0,374	-0,389	0,639	0,864	-25,8

A more intuitive explanation of the differences in the correlation coefficient and the RMSE can be given by looking at figures 7.1 and 7.2. These figures show the obtained trip length distribution from the model and the trip length distribution from the ODiN data for the purpose 'Socrec CA'. The difference in correlation coefficient is the largest of all the trip purposes and there is also a large difference in RMSE. This can be explained by the offset in figure 7.1 in the '2.75-5.5 km' distance bin. This offset is reduced in figure 7.2, which can explain the large difference in RMSE. Next to this, the model trip length distribution follows the ODiN distribution more closely, explaining the higher correlation coefficient. Lastly, it can be seen that the trip length distribution of the model has remained relatively unchanged for the distance bins that were not adjusted in the model subversions. This partly explains that the outcome per distance bin is not dependent between distance bins or on the overall relation of the trip length distribution. This can then be explained by the constraints that are set per distance bin in the model itself.

It can also be seen in table 7.1 that the correlation coefficient is lower for the purposes 'Work' and 'Visits'. The changes made to model version A2 do thus not translate to a better match with the data for all purposes. This shows that the outcome of the parameter estimation depends on the trip length distribution that is used as an input. The model can handle some distributions well, while others are difficult for the model to predict.

As the majority of the trip purposes show a better correlation coefficient and a reduction in RMSE. Model subversion A2 is chosen as the better performing model. Next to this, model A2 solves a problem where there would be a large offset in a specific distance bin which lies outside the desired confidence interval.

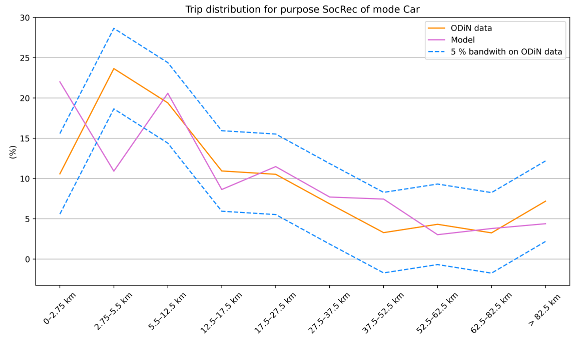


Figure 7.1: Trip length distribution from the model and ODiN data for model version A1

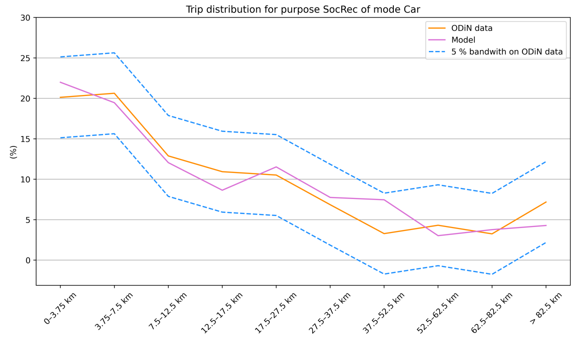


Figure 7.2: Trip length distribution from the model and ODiN data for model version A2

This is a recurring problem in model A1 which is highlighted in figure 7.1.

7.1.2. Workday model O parameters

Parameters that were estimated for the workday model can be seen in table 7.2. Just as the correlation coefficient per subversion and the difference in RMSE. 6 out of 10 purposes show a better correlation coefficient in model O2. Consequently, 'Business CNA' and 'Education CNA' have a correlation coefficient which is lower than 0.35, indicating that there is a very low correlation and the obtained trip length distribution is not comparable to the trip length distribution from ODiN. The trip purposes that do have a higher correlation coefficient show that the increase in the correlation coefficient is not that big, or the correlation coefficient was already at a decent level. For the Saturday model, the changes in the correlation coefficient were larger between the model subversions. This shows that the changes between the subversions might not lead to a better match with the data for the Workday model.

Table 7.2: α, β parameters and statistics for mode Car in Workday model O

Purpose	α_{O1}	α_{O2}	β_{O1}	β_{O2}	Cor O1	Cor O2	Diff RMSE (%)
Work CA	10387,60	6598,54	-0,359	-0,350	0,782	0,651	-0,1
Work CNA	626,45	81,43	-0,343	-0,335	0,809	0,668	-0,7
Business CA	223,26	534,99	-0,458	-0,438	0,706	0,793	-14,6
Business CNA	185,82	403,13	-0,366	-0,332	0,390	0,075	6,7
Shopping CA	308,43	1389,72	-0,592	-0,763	0,923	0,996	-39,6
Shopping CNA	56,82	60,27	-0,580	-0,690	0,963	0,984	-14,3
Education CA	14,69	1132,31	-0,359	-0,314	0,427	0,483	-11,2
Education CNA	47,75	115,75	-0,743	-0,707	0,978	0,335	68,2
Other CA	1893,85	2182,60	-0,424	-0,439	0,818	0,984	-42,5
Other CNA	209,70	189,33	-0,430	-0,438	0,832	0,972	-40,6

As an example of the previous statement, the trip length distributions for the purpose 'Work CA' is shown in figures 7.3 and 7.4. Here, the correlation coefficient is lower and the RMSE is marginally lower. The figures immediately show that the obtained trip length distribution in figure 7.3, better matches the data. In figure 7.4, the obtained trip length distributions hovers around the data, which explains the lower correlation coefficient. The neglectable difference in RMSE can be explained by the offset that occurs in different distance bins.

Based on these correlation coefficients, it is harder to conclude which subversion of the model performs better. The differences in the correlation coefficient are small and the purpose 'Work' performs worse in model O2. The advantage of model O2 is that it solves the offset that is shown in figure 7.1. For the Saturday model, both aspects were improved but this is harder to conclude for the workday model. Especially because a purpose like work is an essential aspect of a workday model, model O1 is not necessarily better than model O1. To still be able to compare the workday model with the Saturday model. The results for model O2 are used in the rest of this chapter.

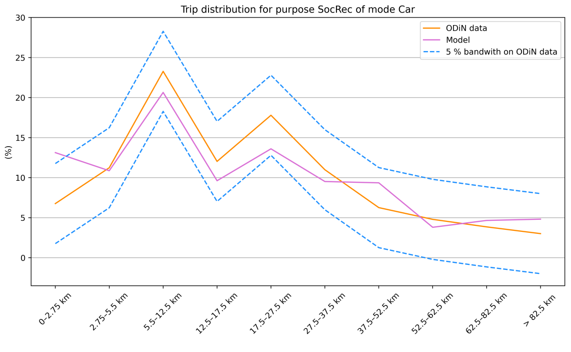


Figure 7.3: Trip length distribution from the model and ODiN data for model version O1

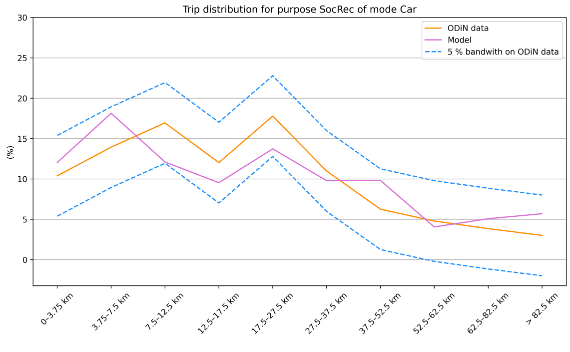


Figure 7.4: Trip length distribution from the model and ODiN data for model version O2

7.2. Internal goodness-of-fit of the model

In this section, the internal goodness-of-fit of the workday and Saturday models is discussed for the results of the entire model, or in other words, for the province of Noord-Brabant. The results of the model are compared with the ODiN data which was used as an input source to the model and a comparison is made with the NVP data. The goodness-of-fit measure that is used, states that the results of the model should fall within 5 % of the ODiN data. This comparison is made for the trip purpose distribution, the modal split and the trip length distribution.

It is not possible to assume that the differences between ODiN and NVP data are fully related to systematic differences in the survey setup, but these differences can also exist because of random errors that relate to the number of respondents or just because a different survey generates different results. In the rest of this chapter, it is assumed that these systematic differences are there and that they are constant throughout the data but it's not possible to make a statement on the magnitude of the systematic differences. This allows for a comparison of the relative differences between the model results and the NVP data.

7.2.1. Trip purpose distribution in the study area

The trip purpose distribution shows the type of trips that are made on an average Saturday in the study area of the model. This should coincide with the original data, as large deviations indicate that there is an error in the model. The Saturday trip purpose distribution can be seen in table 7.3, for the ODiN data, which was was used as input data for the model, the two Saturday model versions and the NVP data which is used to validate the model.

When the ODiN data is compared with the model versions, it can be seen that there are only marginal differences. These differences can stem from the trip generation part of the model, as the later steps of the model don't make changes to the number of trips per trip purpose. The NVP data show larger differences between the trip purposes which likely follow from the systematic differences in the survey setup that were discussed in section 6.4. It can be seen that there are little Other and Sport trips in the NVP data when compared to ODiN. On the other hand, the share of Shopping and Visits trips is higher, while Work and SocRec trips are somewhat equal. These differences can't be fully characterised as systematic differences as there are also random differences in both datasets. Further analysis of this could indicate how large the systematic differences are to allow for an external validation of the model results.

A comparison of the trip purpose distribution of the Workday model in table 7.4 shows similair results for the Saturday model. The ODiN data and workday model show small differences while the NVP data shows larger differences which can't be fully explained yet. Apparently, the reduction in available data for a Saturday model does not directly impact the internal validation for the trip purpose distribution. This is a logical result as the objective of the trip generation model is to match the trip purpose distribution as close as possible. A more local analysis on the trip purpose distribution could indicate what kind of differences occur in the model itself. Such an analysis is performed in section 7.3. To conclude this subsection, both the Workday and Saturday models fall within the range of the ODiN data but this was

Table 7.3: Percentage of trip purposes for ODiN, Saturday models and NVP across the columns

Purpose	ODIN (%)	Saturday A2 (%)	Saturday B2 (%)	NVP (%)
Work	8,05	7,90	7,92	11,14
Shopping	29,36	28,81	28,87	34,74
SocRec	9,68	9,50	9,52	11,59
Sport	11,27	11,05	11,09	5,01
Visits	13,61	13,52	13,32	24,49
Pick up/drop off	7,79	7,64	7,66	6,56
Other	20,25	21,58	21,62	6,47

an expected result.

Table 7.4: Percentage of trip purpose for ODiN, Workday model O2 and NVP across the columns

Purpose	ODiN (%)	Workday O2 (%)	NVP (%)
Work	24,56	23,75	18,96
Business	4,47	4,43	5,74
Shopping	15,41	15,25	23,10
Education	9,34	9,25	4,55
Other	46,21	47,33	47,65

7.2.2. Modal split in the study area

The modal split of the study area says something about the average travel behaviour in an area. The model should therefore represent this modal split correctly. Table 7.5 shows the modal split in percentages for the ODiN data, Saturday model versions and the NVP data. At a first glance, the modal splits are comparable to the ODiN data, which is a good indication that the model performs well and that the NVP data validates these results. Still, Saturday model B2 shows a slightly different modal split with higher car use and lower bicycle use. This could be explained by the different destinations which are introduced in the model. This has an effect on the route that people take and therefore the mode of transport that is suited to travel that distance.

Table 7.5: Percentage of modal split for ODiN, Saturday models and NVP per mode across the columns

Modalities	ODIN (%)	Saturday A2 (%)	Saturday B2 (%)	NVP (%)
Car	71,23	71,45	73,03	70,37
PT	1,52	1,54	1,85	0,97
Bicycle	27,25	27,01	25,12	28,66

Table 7.6 shows the modal split for the ODiN workdays, the Workday model and the NVP data. Here, the NVP data has higher car use and lower bicycle use when compared to the ODiN data and the Workday model. Interestingly, the Saturday NVP data is thus a better match with the Saturday model than the Workday model, but it can also be that the difference in modal split between workdays and Saturdays is not that large in the NVP data in general. Just as with the trip purpose distribution, there is no indication that the Saturday model suffers from limited data and that the parameters which influence mode choice can be transferred to a Saturday model. Other than that, the modal split in the model is largely influenced by the input data so it is expected that the model can replicate this.

7.2.3. Trip length distribution in the study area

The trip length distribution per purpose-mode combination is a result of the α, β parameters that were estimated in the model. Section 7.1 has already shown how the trip length distributions from ODiN are compared with the trip length distributions obtained in the model, this was done to compare the performance of the model subversions, to choose a better performing subversion. Consequently, the

Table 7.6: Percentage of modal split for ODiN, Workday model and NVP per mode across the columns

Modalities	ODiN (%)	Workday O2 (%)	NVP (%)
Car	62,10	62,26	68,59
PT	2,55	2,52	1,78
Bicycle	35,34	35,22	29,64

Trip Length Distribution (TLD) in the model is an indication of the aggregate travel behaviour that the model portrays. If this doesn't match with the ODiN data, the results of the model can not be adequately used in policy testing or other model applications.

As an example of the internal validation of the model per TLD, the TLD for the purpose Shopping is shown for all three modes from the Saturday model in figure 7.5, 7.6 and 7.7. The rest of the TLD for the purpose-mode combinations is shown in appendix D. The 5 % range of the ODiN data is shown around the TLD of Saturday model A2 and B2 and it can be seen that the Car and Bicycle mode both fall within this range. Between model A2 and B2, there are slight differences in the TLD. These differences are a result of how the model distributes the trips in the study area. As model B2 has differences in the trip generation, there are zones which have a different number of trips and these are thus distributed differently. Interestingly, this difference can only be seen in the trip purposes Shopping, Socrec and Sport, as these variables have been changed in model B2. Apparently, the model finds the same trip length distribution as model A2 for the rest of the trip purposes.

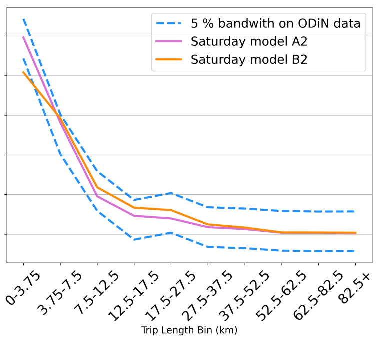


Figure 7.5: TLD of purpose Shopping and mode Car for Saturday model

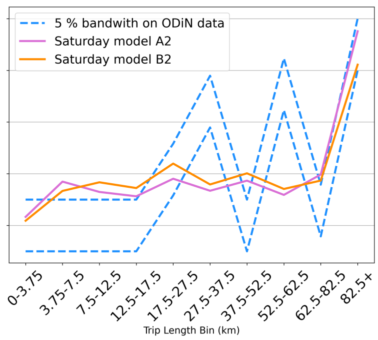


Figure 7.6: TLD of purpose Shopping and mode PT for Saturday model

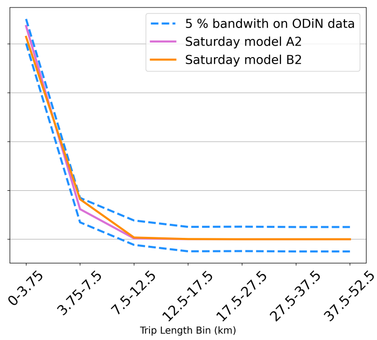


Figure 7.7: TLD of purpose Shopping and mode Bicycle for Saturday model

Figure 7.6 shows that the TLD of mode PT doesn't fall within the 5 % range of the ODiN data. This also occurs for the rest of the PT purpose-mode combinations, which is shown in Appendix D. This means that the PT trips in the model are not a correct representation of the ODiN data but it was also found in the input validation that the ODiN data is not the best representation of the actual TLD via PT. Results regarding PT trips can thus not be used in application studies of the model. Other than that, the Car and Bicycle purpose-mode combinations have shown to fall within the range of the ODiN data. The model can thus correctly portray the TLD from ODiN which makes the model suitable for further analysis.

The TLD for the purpose shopping for all three modes of the workday model can be seen in figures 7.8, 7.9 and 7.10. Apart from the PT mode, the TLD plots are fairly similar to the Saturday model and they adhere to the internal validation of the model. The rest of the TLD plots for the workday model can be seen in appendix D. In this appendix, it can be seen that more PT purpose-mode combinations adhere to the internal validation than the Saturday model but it should be considered whether the ODiN data shows the true TLD that belongs to that purpose-mode combination. As was highlighted in the input validation of the workday model.

To conclude, the internal validation of the TLD indicates how trips are distributed in the model. The Saturday model is able to produce similar results as the workday model and only suffers from data limitations for the PT purpose-mode combinations. On top of that, there is little difference between the developed model versions as there are no fundamental differences between them.

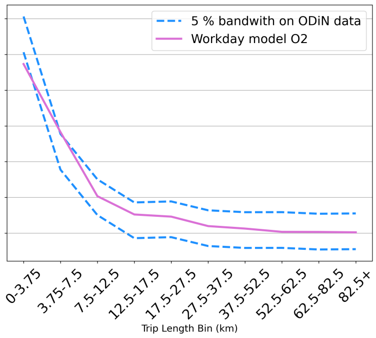


Figure 7.8: TLD of purpose Shopping and mode Car for Workday model

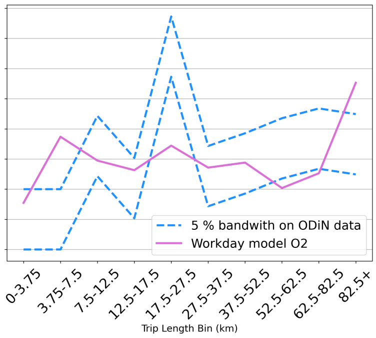


Figure 7.9: TLD of purpose Shopping and mode PT for Workday model

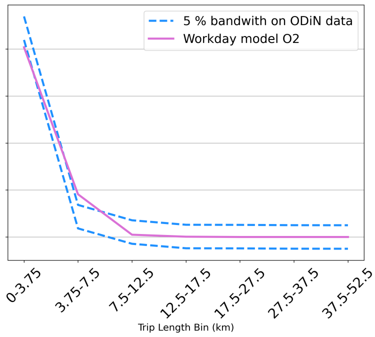


Figure 7.10: TLD of purpose Shopping and mode Bicycle for Workday model

7.2.4. Conclusion

It can be concluded from this section that both the workday and the Saturday model adhere to the internal validation requirements for the trip purpose distribution, modal split and the trip length distribution. This was achieved for model A2 and B2 without any significant differences between them. Only the public transport purpose-mode combinations show unusable results for the model, which was already confirmed by the input validation. Although these internal validation steps are trivial, as the model is made to match these objectives, it shows that the methodology of the workday model applies to the Saturday model and that a similar goodness-of-fit can be achieved. The internal validation could have shown different results, which could have indicated that there was an error in the model. Based on these results, it can be concluded that the results of the Saturday model are comparable to a standard Workday model and that the model can be used for policy testing and model applications, apart from the detailed public transport results.

7.3. Travel demand analysis

The transport model performs well at an aggregate level when it is compared with results for the entire study area. It is even more interesting to investigate the results of the model at a detailed level. Such an analysis can show how the model performs at a smaller scale level and it can give insights into decisions that are made in the model itself. For example, this analysis can show how the trip generation part of the model, that is computed at a zonal level, affects the outcome of the model. Therefore, this section will compare the model results of a a set of areas on a municipal level and on a local scale level. This is done for the trip purpose distribution and the modal split in these areas. An overview of the areas that are analysed, can be seen in figure 7.11 and 7.12.

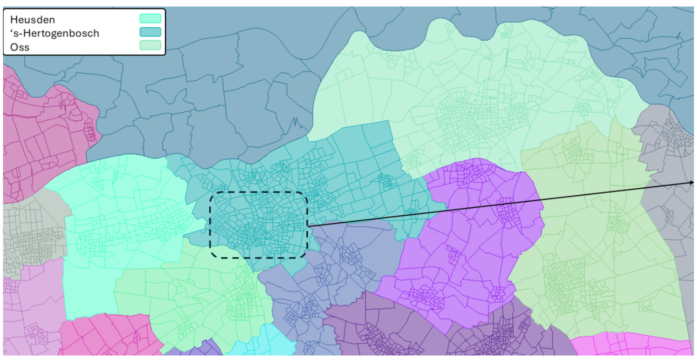


Figure 7.11: Analysed municipalities

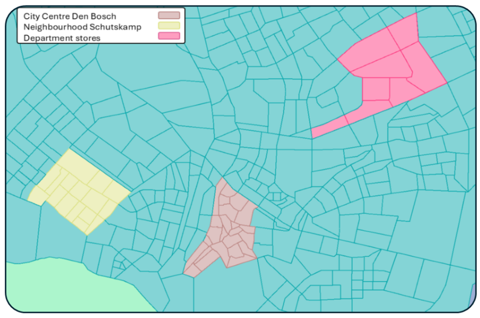


Figure 7.12: Analysed zones in Den Bosch

7.3.1. Trip purpose distribution in analysed areas

The trip purpose distribution of trips arriving in an area is discussed in this subsection and this is compared with NVP data. The tables with these results can be seen in appendix E. As an illustration of these tables, figure 7.13 shows the trip purpose distribution in Den Bosch in percentages.

First of all, analysing the results from model A2 per municipality, showed how the trip generation model affects the trip purpose distribution. This showed that a change in the share of Work and Shopping trips, affected the share of the other trip purposes simultaneously in the trip purpose distribution. This can be explained by the fact that most trip purposes share the same explanatory variable, apart from Work and Shopping, these are explained by the number of jobs or retail jobs. The results of these trip purposes thus scale with the common variable which is the inhabitants per zone. The results in model A2 is thus a simplified representation of travel behaviour, as there is no difference in the number of Visits or Other trips that are predicted in a municipality. However, this also results in unexplainable differences between the municipalities as for example the number of Socrec trips scales with the number of inhabitants and not with the possible destinations. Both these aspects should thus be reflected in the trip-making behaviour of the model which can't show this difference due to the use of the same variable for the majority of the trip purposes.

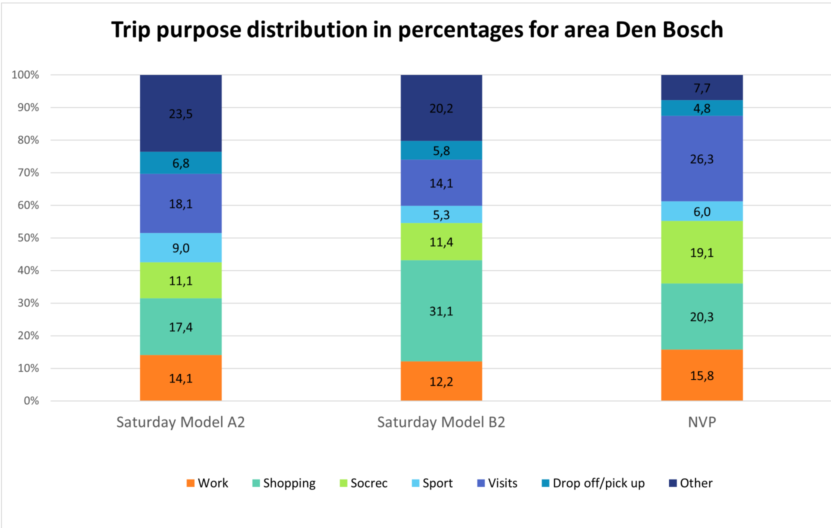


Figure 7.13: Trip purpose distribution for both Saturday models and NVP data for the area of Den Bosch

Secondly, it is interesting to analyse how model B2 improves upon these aspects, as there are more explanatory variables in the trip generation part of the model for the trip purposes Shopping, Socrec and Sport. It is thus expected that there are more differences between the municipalities. This was reflected in the trip purposes Shopping and Socrec which show more differences between the municipalities. A problem seems to occur in the prediction of the share of Sport trips, which show large differences between the municipalities. This is confirmed in Appendix B, which shows that the variable that is used to predict the number of sport trips is not complete. This causes these incoherent results. The rest of the trip purposes again scales with the number of inhabitants in a zone. To conclude, the results for model version B2 are very different from model A2 and there are more differences between the municipalities but the question is, which of the model versions is an accurate portrayal of the true trip purpose distribution.

This question could be answered by using the NVP data as an external validation. Due to the systematic differences, the NVP data is not directly applicable to the results but it is possible to compare the the results of the NVP data between municipalities to discuss differences in the trip purpose distribution and to then compare the relative differences with the results from the model versions. For example, the trip purpose work has a share of trips of 15.8 %, 13.7 % and 12.7 % between the municipalities, if the results of Den Bosch are kept as a reference, the relative differences are: 2.1 % and 3.1 % between the NVP data. If the same calculation is applied to model version A2, the result is 7.0 % and 4.6 % and to B2 it is 3.7 % and 3.3 %. The pattern of the relative differences would then better fit the NVP data for model version B2, although the order of magnitude of the difference is not the same.

Table 7.7 shows the relative differences that were found between the municipalities. It can be seen that for the trip purpose shopping, the relative differences in the NVP have a different sign than for the model versions. This means that the share of shopping trips in Den Bosch is underestimated, while too many are estimated in Heusden or Oss. From this, it can be concluded that both model versions incorrectly portray the relative differences between the municipalities, according to the NVP data. The same is true for the social-recreational and the 'Other' trip purpose, which have an opposing sign.

Table 7.7: Relative differences between the municipalities with Den Bosch as a reference for both Saturday model versions and the NVP data

Purpose - Area	Saturday A2 (%)	Saturday B2 (%)	NVP (%)
Work Heusden	7,0	3,7	2,1
Work Oss	4,6	3,2	3,1
Shopping Heusden	9,3	25,3	-4,1
Shopping Oss	9,5	12,0	-3,7
Socrec Heusden	-2,7	-3,8	4,9
Socrec Oss	-2,3	0,5	6,1
Sport Heusden	-3,0	3,5	-2,1
Sport Oss	-2,0	-2,9	1,1
Visits Heusden	-4,5	-10,9	-2,7
Visits Oss	-3,6	-4,4	-6,6
Drop off/pick up Heusden	-1,6	-4,3	-0,4
Drop off/pick up Oss	-1,6	-2,1	-1,7
Other Heusden	-4,6	-13,5	2,3
Other Oss	-4,7	-6,3	1,7

For the trip purpose Sport, model version A2 matches best to the relative difference in the NVP data, although the share of Sport trips is overestimated in Oss. Consequently, the trip purpose visits has the correct sign for the relative difference, but the differences between the municipalities do not match. From this analysis it can be concluded that both model versions have some trip purposes which show a match on the relative difference between municipalities. Next to this, some trip purposes are over- or under estimated for some municipalities. A remark on this conclusion is that the random error in the NVP data can influence the trip purpose distribution which is the basis for this analysis. Therefore, the confidence interval of the results should be included in this analysis.

Trip purpose distribution in Neighbourhoods of Den Bosch
The same analysis is carried out for neighbourhoods within the municipality of Den Bosch. These are the city centre of Den Bosch, Neighbourhood Schutskamp and an area with department stores. The trip purpose distribution of these areas can be seen in appendix E, for both Saturday model versions and the NVP data.

The results of this analysis further exemplify how the variables in the trip generation model influence the trip purpose distribution in the model at a neighbourhood level. Especially in an area such as the city centre or the area with department stores, the share of shopping trips was found to be high while the remaining trip purposes had a low share or they were close to zero, as there are no inhabitants in the area with department stores. This shows how the results of the model are different at a neighbourhood level. Next to this, the analysis shows that model B2 can better show differences between trip purposes but that better trip attraction variables are required for the trip purposes that are now predicted by the number of inhabitants in a zone. For example, the share of Visits trips or drop off/pick up trips could differ in different areas of a city, but the model is currently not able to show this.

The NVP data shows less differences between the areas than the model versions. Making the NVP trip purpose distribution not comparable to the model version itself for the city centre and the neighbourhood Schutskamp. The NVP data is comparable for the area with department stores but it should be noted that these results are based on a smaller sample size than for the municipalities. Next to this, the panel effect in the NVP data can make sure that the NVP trip purpose distribution shows the trip purpose distribution of people that live in the area, while the trip purpose distribution in the model shows travel behaviour of people visiting the zone once for shopping purposes.

The results also give reason to further verify the results between the model versions to investigate the impact of the changes that were made and it shows that large differences can occur in the trip purpose distribution between areas, whereas the trip purpose distribution of the municipalities showed an aggregate level.

7.3.2. Modal split in analysed areas

The modal split of an area can indicate differences in travel behaviour between municipalities. Analysing this at a municipal level, allows for an analysis of how the model portrays the modal split, this can be seen in table 7.8. Just as with the modal split on a regional level, both model versions show slight differences in the modal split. Interestingly, the use of public transport is higher in model B2 for all municipalities, while car and bicycle use differ. This can relate back to the differences that were seen in the trip purpose distribution, as different trip purposes come with different travel behaviour in terms of modal split or trip length distribution. Alternatively, it could be that the public transport use is lower in municipalities that weren't analysed, so it is uncertain how the model has come to these changes. Another observation is that the NVP data matches the differences between the municipalities. Based on that, the modal split in Saturday model B2 seems to perform better than Saturday model A2. Still, it is uncertain how this holds for other municipalities in the model.

Table 7.8: Percentage of modal split for trips arriving in a municipality, for both Saturday model versions and NVP data.

Modality	Saturday A2 (%)	Saturday B2 (%)	NVP (%)
Den Bosch			
Car	69,67	65,77	65,78
PT	1,89	2,81	3,51
Bicycle	28,44	31,42	30,72
Heusden			
Car	78,53	80,49	83,42
PT	0,12	2,68	3,13
Bicycle	21,34	16,83	13,44
Oss			
Car	68,88	68,84	70,25
PT	0,58	2,89	3,17
Bicycle	30,54	28,28	26,59

Modal split in the neighbourhoods of Den Bosch

The same analysis is carried out on the modal split of trips arriving in the neighbourhoods in Den Bosch. This can be seen in table 7.9. Differences between the model versions are again small, except for the city centre of Den Bosch. The increase in car use can be explained by the increase in shopping trips which are predominantly made by car. It is also interesting to note that the bicycle use is quite high in the city centre, this could be an effect of the parking constraints set in the model or other model properties which limit car use in the area. Additionally, the use of public transport is higher in model B2 for all the municipalities.

A comparison with the NVP data shows that the neighbourhood Schutskamp and the area with department stores matches well for both model versions. Although the share of public transport trips is zero in the NVP data. This can be explained by the low sample size that is used from the NVP data. Consequently, the NVP data doesn't match well with the modal split in the city centre of Den Bosch, as the car use is higher in the NVP data. This can be due to sampling errors in the NVP data or because of specific model properties which change the modal split in such an area. Due to the incomparable results of the city centre, it's harder to conclude which modal split is a better match with the NVP data.

7.3.3. Conclusion of travel demand analysis

This analysis has showed the differences between municipalities and neighbourhoods in the trip purpose distribution and modal split. From the trip purpose analysis it can be concluded that the current variables used in the trip generation part of model A2, pose a simplistic view on Saturday travel. Model

Table 7.9: Percentage of modal split for trips arriving in neighbourhoods of Den Bosch, for both Saturday model versions and NVP data.

Modality	Saturday A2 (%)	Saturday B2 (%)	NVP (%)
City Centre Den Bosch			
Car	22,52	33,61	55,72
PT	2,34	3,85	4,90
Bicycle	75,13	62,54	39,38
Neighbourhood Schutskamp			
Car	61,69	61,45	64,18
PT	1,85	2,12	3,52
Bicycle	36,47	36,43	32,31
Department stores			
Car	76,05	80,77	89,67
PT	0,52	0,78	0,00
Bicycle	23,43	18,45	10,33

B2 partly solves this but the variable Sport seems to show incorrect results. This is confirmed in appendix B, which shows additional results on the adaptation that was made for model B2. The additional results show that there are large differences in production and attraction within a municipality, which is an unrealistic portrayal of the Sports trips.

In a comparison of the relative differences between the municipalities, the NVP data was used as a reference and from this comparison, there is no definitive answer whether model A2 or B2 is a better portrayal of Saturday travel behaviour. Some trip purposes were estimated as too large, while other trip purposes are underestimated. In terms of modal split, the analysis between municipalities showed that the model is comparable to the NVP data where model B2 seemed to perform slightly better. Lastly, these results contrast the internal validation of the model in section 7.2, by showing how travel behaviour is portrayed on a more detailed level.

7.4. Conclusion

The goal of this Chapter was to answer sub-question 4: *How does the developed model perform when compared to travel data on a Saturday?*. Section 7.1 first shows why Saturday model version A2 was able to perform better than Saturday model A1 in it's ability of matching the trip length distribution from ODiN. However, both model versions performed poor in the estimation of public transport trip length distributions, due to limited data. This means that detailed public transport results can't be used in modelling applications. Section 7.2 then shows that both the workday model and the Saturday model adhere to the internal validation when compared with the ODiN data on a regional scale, apart from the trip length distributions for public transport. This might seem as a trivial result but it shows that a Saturday model can be made with the same setup as the workday model in this research. Next to this, a comparison with NVP data was not made fully due to systematic differences between the ODiN and NVP data. The local travel demand analysis in section 7.3 shows in more detail how the model works. This confirms that the variables chosen for Saturday model A2 are a simplistic portrayal of Saturday travel behaviour. Model B2 is able to bring more differences between the trip purposes, but the trip purpose Sport shows peculiar results. A comparison with the NVP data showed that neither model versions showed consistent results with the travel data and that a better comparison is still required. Conclusively, the developed Saturday model performs well on the ODiN data, but a better comparison with an external data source is required to draw this conclusion.

8
Discussion

This chapter will discuss several aspects of the thesis to showcase limitations in the research and how this has affected the outcome. Furthermore, the discussion highlights how the developed model is fit-for-purpose by assessing the functionality, realism and benefit of the model.

8.1. Discussion and limitations of the literature review

The literature review in this research has tried to create a comprehensive overview of differences in work- and weekend travel, but also on modelling approaches that could be used in this research. The topic of finding suitable modelling approaches is quite broad and it didn't fit in this thesis to create an overview of all the possible modelling approaches. A better starting point of this research would have been to think about what the most suitable model could be to model Saturday travel behaviour but that was not done. This made it hard to structure the literature review as a whole, as it was unclear at the start how the literature would contribute to the model development part of this research. It is thus possible that important sources were missed in the literature, which could have contributed to this research.

An example of this is that at a late stage in the research process, a set of Activity Based Models (ABM) were found that model the weekend. At first, it was assumed that the majority of papers on weekend models were found but this was not the case. ABM's model travel behaviour in a disaggregate manner as micro data is used to model travel behaviour of individuals. This is a very different approach than the four-step model which models travel behaviour in an aggregate manner, depending on the model components that are used. The ABM's that were found in the literature, model the weekend as part of a model that models the entire week. Next to this, ABM's are being developed conceptually to correctly include the variability of weekend travel (Haghighi & and Miller, 2025) (Moeckel et al., 2024) (Mallig & Vortisch, 2017). Using an ABM can thus deliver a more realistic and extensive portrayal of weekend travel behaviour over an aggregate model but it should also be noted that a more advanced model such as an ABM is not necessarily better (Zhong et al., 2015). Both approaches have benefits and disadvantages that should be taken into account when the choice is made for a certain modelling paradigm to model a weekend day. Next to that, more practical decisions should be made when choosing a modelling paradigm, such as the effort required to make a model. In that case, an aggregate model costs less effort.

Apart from the choice for a certain modelling paradigm, models can also have different components which have their own benefits and disadvantages. Such a model component is the prediction of destination choice. To do this, either a gravity model, a discrete choice model or a different approach can be used. The literature review in this research has mainly focused on the existing model components that are used in the BBMA model so it could well be that a modelling approach exists within a model component that can better model weekend travel.

The choice for a certain model or model development can also be very practical and it's difficult to distinguish how the state of models that is used in practice, differs from the state of models in literature.

An example of this is that there is a lack of development in trip generation models in literature, while these models still set the standard in practice.

The literature review has mainly looked at differences that occur in work- an weekend days in the travel demand side, but not on the travel supply side. Differences in the travel supply side can also affect weekend travel, so they should be studied as well. Two recommendations can already be made on which aspects of travel supply should be studied. First of all, Calvert et al., 2016 have shown that highway capacity is 4 % lower on weekend days, when compared with a workday. This pleads for using different capacity values in a weekend model, or even a variable capacity for the time-of-day. This change in road capacity may come from more inexperienced driver's on the road which keep a longer distance to the car in front, this can then cause a lower capacity on the road. It should be noted that there can be other factors which influence the road capacity which weren't analysed in the study. Secondly, the impact of reduced public transport schedules is not studied in this research and it should be considered how this affects the outcomes of the model and if this is a good representation of public transport use in the weekend.

8.2. The use and application of ODiN data

ODiN travel data is used in this research to estimate a transport demand model. This comes with a set of limitations and these are discussed in this section.

First of all, the data of multiple ODiN years is used to estimate the model, namely, 2018, 2019, 2022 and 2023. The years are stacked to get a higher number of observations, which is used to estimate the model. This is standard practice in the estimation of transport models but this also reduces the information in the data that is used as input for the model. The goal of ODiN is to weigh the data from the respondents in such a way, that the data is representative for the total number of trips that are made in the Netherlands in that year. When ODiN years are stacked, the characteristics of each ODiN year are then lost in the aggregation and the input data becomes a representation of average travel behaviour of multiple years. For example, between 2018 and 2023 there can be an increase in the total number of trips that is made, due to a higher number of inhabitants in the Netherlands, this difference is then lost when the ODiN years are stacked. Especially for a Saturday, this can mean that data is used which is not representative for an average Saturday, due to changes in travel behaviour between years and because less data is available on a Saturday.

Secondly, the data-analysis that assumes that tour-making is less complex in the weekend could have been done in a more thorough manner. Correctly analysing this, would require a more complex approach. For example, by identifying the main activity in a tour, based on activity duration or by investigating which trip purposes are mainly combined in a tour in the weekend. Another assumption was that round trips, or a trip from A to A, was not included in the input data for the model. An analysis was done to check whether the exclusion of these type of trips is justified and it was found that the majority of these trips were walking trips. Hypothetically speaking, these trips can still have a large effect on a transport system, as the distance of these trips can be long for a car ride or bicycle ride. So it can be considered how this affects for example, the bicycle network on a Saturday.

Chapter 4 derives a trip purpose distribution for the Saturday from ODiN data. This makes the research dependent on the trip purposes that were defined in ODiN. It is possible that the definition in ODiN is too broad for some trip purposes, making it difficult for respondents to identify the correct trip purpose of a trip. For example, a hobby trip should be categorised under the ODiN definition sport/hobby but it's possible that people categorise this as a recreational activity. Next to this, it is not known whether the majority of sport/hobby trips is a sport or a hobby trip. This makes it difficult to assume if the travel behaviour within ODiN trip purposes can be described as a specific type of trip purpose or that the travel behaviour is comparable to other trip purposes. This has consequences for the trip purpose distribution that is derived and it should be considered if a different trip purpose distribution should be considered for the Saturday. Nevertheless, if the ODiN survey would have used a differentiation per activity type, as can be seen in Spinney and Millward, 2011, the ODiN survey would have to include more than 40 activity types too achieve a realistic set of activities. This is not realistic to include in a large survey like ODiN and the trip purposes would have to be aggregated later on for a model.

A remark should be made on the method that is used in the ODiN data to obtain the total number of trips that are made. The goal of the ODiN survey is to give an estimation on the total number of trips that were made in the Netherlands in a year. This is done by assigning a weight to each respondent, that reflects the weight of the movements of the respondents in comparison to the total number of trips that were made in the Netherlands. These weight factors are determined based on the characteristics of the survey respondents and the total population of the Netherlands. The CBS, 2024b states that the weights are also representative on a regional level to obtain the total number of trips in a region. The question is whether this assumption still holds when the data is reduced to the Saturdays. Especially because the data is weighted on person characteristics instead of trip characteristics. This could mean that the respondents on a Saturday are not comparable to the total population. As a result, the portrayal of average travel behaviour on a Saturday could be different.

8.3. Use of an operational model

This research has used the BBMA model to create a preliminary Saturday model. This has brought benefits and disadvantages in the research process which will be discused. First of all, using an operational model such as the BBMA model, reduces the amount of work that is required to create a transport model. Creating a transport model from scratch would require a tremendous amount of work and that would not be feasible for a Master's thesis. The use of the BBMA model directly creates results that can be used in practice, as not all modelling approaches that can be found in literature are applied in practice, due to the amount of work that goes into these adaptations. Disadvantages of using an operational model is that the researcher is bound to certain assumptions that are made in the model or some aspects of the model can not be changed as the software doesn't allow this. Next to this, some aspects of the model, such as the trip generation model, could not be analysed in a scientific way. An example of this is that the error term in a trip generation model is usually used to show the uncertainty of the results but in the model that was used, this error term was minimized in an iterative way. Such hurdles in the research process are a good reflection of how models are made in practice, a comparison between such a practical model and a model described in literature is rarely made so it's difficult to define what the major differences is between these models. Conclusively, the differences that were found in this research process have led to a set of recommendations in the next Chapter.

A different limitation in the model setup was that this was the first time that the standard workday model was estimated on ODiN data. Previously, the BBMA model was estimated with the OViN dataset but for this research the ODiN dataset was used. Although they are both travel surveys, the results are not comparable, due to differences in the survey setup. As a result, the outcome of the reference model is different from the model that was previously estimated on OViN data. Because of that, the reference model is not calibrated on traffic count data, which is usually done for these kinds of models. Finally, a comparison between the previous model, and the model estimated with ODiN has not been made in this research as the goal was to create a Saturday model. It could thus be that the workday reference model can achieve a better model fit than presented in this research.

8.4. Discussion on modelling adaptations

This research has focused on finding adaptations to make a Saturday model but this research has not started with the question how a transport model is made. The adaptations that were discovered lead to trivial adaptations to the model but it is likely that similar adaptations were made to the model if the building steps of a transport model were followed. Now, it is of course important to justify the decisions that are made with literature and data but this observation also tells something about the suitability of aggregate models to model travel behaviour. The data that is used as an input to the model is aggregated, the outcome of the model will also deliver aggregated results and this limits the way in how travel behaviour is portrayed. This is because the variability between and within people is lost in the aggregation. Making an aggregate Saturday model might thus not require a very different approach than for a workday model, as aggregated Saturday travel is not very different from aggregate workday travel. It is possible that a different approach is thus required for a disaggregated Saturday model, as this is an approach that tries to underpin the choices that individuals make and these choices were found to be different at an individual level.

The adaptations that were found in this research could achieve a higher level of detail in terms of how the adaptations should be modelled. Most of the modelling adaptations are described in a simple manner, but this research does not reflect on the feasibility of the proposed adaptations. Alternatively, the adaptations presented in this research present demarcated research gaps which can be used for further research.

8.5. Model results

The parameter estimation that was performed in this study was difficult to analyse as the estimation of the parameters is done in an iterative algorithm. This makes it difficult to derive meaningful conclusions on the performance of the model as it is unclear how the model optimises the outcome. Therefore, it was difficult to derive a meaningful analysis from the α, β parameters themselves. Additionally, the different distance bins were mainly used in this research to solve a large offset in the trip length distribution, but this problem could also arise from the algorithm that is used in the parameter estimation process. Using different distance bins is thereby an easy solution but it doesn't allow the modeller to use a desired set of distance bins in the model. It is therefore recommended to investigate where this problem arises.

Consequently, the effect of using different distance bins can have an effect on the short trips that are made in the model. The original distance bin was from 0 to 2.5 km but this was changed to 3.75 km. The distance of 2.5 km can also be a cut-off point which contains specific type of trips which now fall under 3.75 km. it could thus be that the distance bins, generalise the travel behaviour in a wrong way.

The parameters were now evaluated on the correlation coefficient per purpose-mode combination, to say something about model performance. It is a better practice to evaluate the results of an estimation with a single statistic. Comparing the number of results that perform better is also a single statistic, but this statistic doesn't consider the size of the improvement per trip purpose and this doesn't explain to what degree the improvement should be deemed as important. A statistic that is for example used in choice modelling is the log-likelihood, which allows for a direct comparison of models, but it is even better to compare a multitude of these statistics in the evaluation of two models.

8.6. The use of BAG-data and NVP data

BAG-data was used in this research to create trip attraction variables for Saturday model B2. It is important to mention that the BAG-data was not subjected to an extensive filtering process and that it is also not the best dataset to use for this purpose, as the building use is defined in a very generic way. A more detailed dataset can improve the quality of the variables for the trip-generation model.

NVP data was used as an external data source to validate the outcome of the model. Due to the systematic differences between ODiN and NVP, a correct comparison could not be made. One thing that could have been done is to compare the width of the confidence interval of the ODiN and NVP data for the model results. Although the results would then not be the same, this can indicate what the reliability of the results is. Alternatively, holdout could be used to validate the model, although this will greatly reduce the available data for the model. Apart from travel surveys, other data sources could be used to validate or calibrate the model such as traffic counts.

8.7. Reflection on the purpose of the model

The Saturday model that was developed in this research was a first test to see how a Saturday model should be developed but also on what purpose a Saturday model can serve. This section reflects if the model can be used for it's intended purpose. This is done on three aspects. First, the functionality of the model is reviewed. A functionality of the model is if it allows for policy testing or scenario testing, so how can the model be used? Secondly, the realism of the model is discussed by reflecting on the validation of the model, or in other words, how accurate is the model a portrayal of Saturday travel behaviour. Thirdly, the required effort and the benefit of making a Saturday model is discussed. Does the effort for example justify the benefits of a Saturday model. Together, these three aspects summarise whether the developed model is fit for it's intended purpose.

The functionality of the developed model should be comparable to the reference workday model that was used to make the Saturday model in this research. However, not all functionalities of the model have been verified in this research. The model is able to deliver traffic intensities for an average Saturday and this is thus an outcome that can be used. Next to this, the model has the possibility to do policy tests but it has not been verified if these results are realistic. Relevant attributes will have to be included in the model first before it can really be used in policy testing. Additionally, policy tests for a Saturday might focus on other aspects than policy tests for a workday. As a result, policy tests for a Saturday might require a different setup or additional variables which are not present in the model. Another common functionality of a transport model is to forecast a future year. This has not been done in this research but it is also likely that a correct estimation of a future year requires different attributes in the model than in a workday model. It's also a different question what the relevance is of policy testing and the estimation of a future year for a Saturday, but to do so, this functionality should be in the model.

The realism of the model is defined by the aggregation level that is used in the model. On a regional scale the model can portray Saturday travel behaviour in an aggregate form but the model struggles to show differences in travel behaviour on a smaller scale level. This is logical, as the model is based on aggregate zonal variables. Consequently, the model was validated on the ODiN dataset which was used to create the model. The NVP dataset that was used, contained a lot of systematic differences, which hindered a correct validation of the results. Normally, a different method is used to validate and calibrate the results of the model. This is usually done with measured traffic intensities on certain locations. Although the question can be asked whether this method is applicable for a Saturday model. This would require measurements for a Saturday and these are not always available in all locations. Next to this, the realism of the model also relates to it's purpose. If a model should be good at predicting traffic intensities, then that should be used in the calibration. If this isn't the case, it's better to validate the model on it's portrayal of travel demand. Next to this, more adaptations could have been included in the model to increase the realism of the model, but it has to be said that the adaptations that were made already show a large part of Saturday travel behaviour. The realism of the model is mostly limited in the way in which the model, models travel behaviour.

Lastly, the required effort to make a Saturday model and it's perceived benefit is discussed. This is an important question to answer as creating a transport model requires a lot of work, the benefit that a model can offer should thus justify the effort. Otherwise, this is a waste of resources. In that sense it's also good to separate two types of effort that is required. The first is the effort that is required to develop a Saturday model from scratch, this thus includes the effort for the data-analysis to find attributes and a relevant trip purpose distribution or the effort that goes into refining aspects of the model, such as in the trip generation step. The second type of effort is the effort that is required to create a model based on a workflow. The first type of effort is not comparable to the second type of effort as model development can take years, but the second type of effort becomes important when a Saturday model has undergone a set of refinements. In that case, the effort required to make a Saturday model will probably be comparable to the effort that is required to make a workday model and the effort will then also weigh up to the benefits. Whether the first type of effort can be justified by the benefits of a Saturday model is a harder question, but it's also the most relevant question at this point in model development. However, that is not something that can be answered, based on this research as there are still many open questions.

What can be answered, is if the effort that was put into this research, weighs up to the benefit of the model that was created. Considering the level of detail that is acquired in the model, the model might already be usable for one of the use cases with a few improvements. Which is to compare workday and Saturday traffic flows with each other. That is something which the original workday model was meant to do, so it's likely that the Saturday model can also achieve this, as long as the typical Saturday destinations are adequately incorporated in the model. Next to this, the developed model can be a good starting point for future research. If the Saturday model is developed further, that would already justify the effort that has been put into this research.

To conclude this section, the functionality and realism in the developed model are lacking or some questions remain open-ended, which makes it unclear whether the developed model is fit-for-purpose. Alternatively, it can also be that the model can already be used for one of the use cases, which is to compare workday and Saturday traffic flows with each other. This would make up for the lack of realism and functionality as this use case fits the aggregate nature of the model. Secondly, the benefit of the developed model lies in it's ability to be used as a starting point for future research, as it also provides a well-grounded set of adaptations to further develop a Saturday model.

9 Conclusion and recommendations

The main conclusion of this research is that an existing workday transport model can be adapted by using different trip purposes and Saturday travel data to create a preliminary Saturday transport model. The main changes in the model are required in the trip generation step, while other adaptations can be made to increase the realism and functionality of the model, to portray average Saturday travel behaviour. A major limitation in the development of a Saturday model is the availability of data to make the model. This lack of data could prevent further refinement of the model, if advanced adaptations are implemented in the model.

The Saturday model that was created in this research, is deemed to be adequately fit for purpose. The model can be used to compare Workday and Saturday traffic flows which means that the model can be used in one of the use cases that was found in the research. This use case fits the aggregate nature of the model and it can thereby fulfill a purpose. Secondly, the benefit of the developed model lies in the starting point that it delivers for future research. A well-grounded set of adaptations can be used to further develop a Saturday model or lessons can be learned from the model that was developed in this research. Not all, proposed adaptations can be directly implemented in a Saturday model as it was found that some adaptations require a disaggregate approach to model the intricacies of Saturday travel behaviour. An Activity-Based model might be the best solution to do this but an aggregate approach is still suitable.

Next to this main conclusion, the sub-questions in this research have each contributed to the research, so that a preliminary Saturday transport model could be made. The conclusion per sub-question is listed below.

Both Chapter 2 and 4 have answered sub-question 1 by listing the main differences between work- and weekend day travel. These differences showed that travel behaviour is fundamentally different in the weekend due to the different temporal and spatial constraints that people experience in the weekend. This results in more leisure-oriented trips in the weekend, which differ in destinations from the average workday. The variation between people is also larger in the type and number of activities that is performed than on workdays, and the variation within people is larger for consequent weekend days than on workdays. Lastly, Saturdays and Sundays are characterized by different trip purposes and should thus be regarded separately.

Sub-question 2 is answered in Chapter 3, by creating a set of adaptations from differences in work - and weekend day travel that can be used to develop a Saturday model. The adaptations are ranked on their required effort and perceived benefit to show which adaptation is the most relevant. The rest of the chapter contributes to these adaptations by first of all showing that there is no clear modelling approach to create a weekend model but this doesn't mean that the development of a weekend model should be limited conceptually. Secondly, a review on non-work trip purposes highlight multiple modelling approaches that can be used to refine certain components of a weekend model.

Chapter 5 partly answers sub-question 3 by deriving a set of use cases and the possible purpose of a weekend model from interviews and literature. Three use cases were identified in which it was clear that a Saturday model could assist in policy-related problems and thus also have a clear purpose. The use cases all require the development of a basic Saturday model, from which each use case then requires some minor changes before it can be used. However, sub-question 3 could not be fully answered as the question remains how precisely a weekend model can assist in the use cases that were identified. Next to this, it is unclear how weekend days should be treated in comparison to workdays in policy development.

The results of the model in Chapter 7 were used to answer sub-question 4. This showed that the developed model performs well on a regional level, while the detailed results show that the model is not able to correctly capture differences in distribution of trip purpose between municipalities. The analysis was able to show how the developed model versions work in detail and it was found that Saturday model A2 is a simplistic portrayal of Saturday travel behaviour and Saturday model B2 is not directly able to improve upon this.

To conclude, this research has proposed a set of adaptations to develop a basic Saturday model and has thereby created a starting point for the development of Saturday models within the four-step-modelling framework. As a second step, the literature review on travel behaviour can be used to derive methods for further data-analysis on Saturday travel behaviour or to identify variables which can be used in a Saturday transport model. Thirdly, the literature review on modelling approaches gives ideas for adaptations for a Saturday model, which could also be used for an Activity-Based model. Lastly, this research has identified a set of use-cases and a possible purpose for a Saturday model. Thereby, it paves the way for research and discussions on how Saturday travel behaviour should be regarded in the development and maintenance of transport systems.

9.1. Recommendations

As this research has created a first basic Saturday model, a number of recommendations can be made to Goudappel, policy makers and future research. However, all recommendations are potentially useful for all reader's, as a scientific recommendation could apply to the company and vice versa.

9.1.1. Recommendations for future research

First of all, to the author's knowledge, this is the first research that develops a basic Saturday model. Thereby tackling numerous aspects of the development of such a model, ranging from the data-analysis to the purpose of the model. Therefore a number of recommendations can be made on model development. An overarching aspect that should not be forgotten in this case is that it is essential to balance the effort that goes into model development, with the intended purpose or outcome of the model. Preferably, the development of a Saturday model should be delayed before it is clear how it can be used in policy development, but this presents a certain ambiguity. Which is that the model should be developed, before it can be used. It is therefore recommended to perform these steps simultaneously before further research is carried out that focuses only on model development.

A major limitation of the development of Saturday models will be the available data. Alternative methods should be explored to check whether country-wide travel data can be used on a regional or municipal level, instead of data from the area itself. Especially in a model which uses aggregate statistics as an input to the model could benefit from additional data to estimate a model. Models which utilise the origin and destination of travel data are not suitable for such an approach

The proposed adaptations form a direct starting point for future research, as these can be used to further adapt an existing workday model. The implementation of some adaptations can be straightforward while others require a data-analysis or a process of trial-and-error. For example, when the Value Of Time parameters have to be researched, or when adjustments are made to a trip-generation model. From such a research, insights can be generated on how an adaptation can be implemented and which trade-offs need to be made in model development. Next to the development of a basic Saturday model, future research can be focused on a specific use case for a Saturday model which is presented in this research.

The adaptations can be implemented in the BBMA model, but also in other workday models with a different model setup. It should then be considered how each adaptation fits in the setup of the model and how it can be implemented. This can give insights on how the list of adaptations can be transferred to other model setups and if the list should be refined. Additionally, the transferability of the set of adaptations to a possible Sunday model can be researched, as it was found that Saturday has different travel behaviour than Sundays. Next to this, it would be better to first develop a Saturday model conceptually, instead of choosing a modelling framework in advance. Both the four-step modelling framework and activity-based models are suitable to model Saturday travel behaviour, so it should be considered at what level of detail the model is fit-for-purpose.

To summarise, a Saturday model can be further developed with the proposed adaptations, without losing the connection to the intended purpose and use cases of the model. Alternatively, it should be considered whether an Activity-Based model is better suited to model Saturday travel behaviour then an aggregate approach.

9.1.2. Recommendations to Goudappel

As was highlighted in the Discussion Chapter, it's difficult to compare an operational model with models developed in literature. Still, some recommendations can be made to the company, based on the literature and through lessons that were learned in the transformation of the workday model.

First of all, it can be considered whether a household or person-based trip generation model can improve the current zonal-based approach. One of these approaches can provide a more detailed level of trip generation as it allows for the use of explanatory variables at this level of detail (Kim et al., 2021). A result of this could be that differences in trip generation between zones, caused by car ownership or income, is better reflected in the model. This could be done for the current workday model and the Saturday model. It is possible that different variables can better explain the trip generation behaviour on both days and that it is harder to make a correct model for the Saturday. To conclude, it should be considered if this improvement in trip generation is a desired result for the model as a whole or whether this doesn't fit the purpose or intended outcome of the model. Moreover, the literature has seen little development in trip generation models, so it is possible that this type of models have reached a technical limit and that improvements should be sought in the quality and amount of data that is used.

Secondly, this research used BAG-data to improve the trip attraction for some trip purposes. It is recommended to explore data sources with a higher level of detail than the BAG-data, such as OSM (Klinkhardt et al., 2021) or other data sources. Although the BAG-data contains information per address, the categorization of the data is too aggregate to use it for trip purposes in a Saturday model.

Thirdly, this research has developed a Saturday model on a regional scale. It should be tested whether the methodology of this research can be applied to models with a smaller scale level. It could well be that there is a lack of ODiN data to estimate a transport model on a municipal scale level for a Saturday. If so, a solution might be to collect additional data in that area. The available data from the ODiN survey will remain limited, as only a small share of the data from new ODiN years will be on Saturday. Next to this, it should be considered at what degree a regional model should realistically portray travel behaviour at a smaller scale level. In this research, results of the model were analysed on a municipal and neighbourhood level. This showed that the differences mostly stem from differences in the trip generation part of the model and that the model does not correctly show travel behaviour within a municipality. If this is a desired result, calibration efforts of the model could be aimed at this municipal scale level to improve the results.

Lastly, it is recommended to remove the variable: 'Car Availability', in the Saturday model. The variable is used in the workday model to assure that there is a group in the model which is more likely to take Public transport or the bicycle than the car and to have a separate group in the trip generation model. It might be better to remove this classification and implement car availability in a different manner as it could increase the available data per trip purpose. Especially because the modal split can be derived without the classification.

9.1.3. Relevance for policy makers

First of all, the literature review on differences in travel behaviour between work- and weekend days is relevant for policy makers as workday policies will have a different effect on weekend days. An example of this is the higher car occupancy rate seen on weekend days, promoting car sharing could thus not have the intended effect on weekend days, as this doesn't match the actual travel behaviour. Another example is that public transport is mainly used by people who use public transport in workdays. Promoting public transport on weekend days might thus have a lower effect as most people don't consider public transport as a travel alternative in the weekend. Additionally, travel demand in the weekend might not match with the service that is offered by public transport, so this could be researched. Similarly, travel behaviour during the week is related to travel behaviour in the weekend. This means that each day can not be regarded separately but that policies have an effect on the entire week.

Secondly, the use cases for a Saturday model that are presented in this research are directly relevant for policy development on a Saturday. An example of this is the estimation of traffic emissions on a Saturday, which can be improved by using a basic Saturday model over the previous method. Next to these use cases, it can be researched whether other use cases are relevant for policy development on a Saturday. An example of this can be to predict traffic flows around an event location in combination with regular Saturday traffic or to predict the impact of road works on Saturday traffic with a Saturday transport model.

Finally, the relevance of this research is that it showcases how an understanding of weekend day traffic and it's relation to the development and maintenance of transport systems has been lacking. From this, the question remains how weekend days should be considered with respect to workdays in policy development. A central part in answering this question is that peak traffic conditions should not be the only criteria on which a decision is made but on broader criteria which consider wellbeing, safety, accessibility and more.

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A

Appendix A: Interview summaries.

A.1. Interview script

The interview will start with the introduction below and the interviewee is asked about the content of their work. After that, a small introduction is given about goals that a government can have to maintain or improve a transport system to advance to the first two questions. The third question is then a specific question about weekend-related phenomena and the fourth question is about the possible use and purpose of a weekend model.

I am working on my master thesis, in this research I am looking at how a transport model can be developed for the weekend. This includes determining what the use and purpose is of a weekend transport model. Are there for example specific cases in which municipalities would want to have more insight, or is the weekend understudied due to other priorities. This helps me to understand how the model can be developed and how it will be used in the future.

What do you do at … ?

As a municipality/province, you can have certain transportation goals such as: increasing the quality of bicycle lanes, developing areas with mixed land-use or making the city centre car-free. With these goals in mind..

1. What goals are applicable to the weekend?
2. What would weekend-specific goals be?
3. What are travel/traffic characteristics of your municipality or destinations that are important to know about when creating a transport model for the weekend?
4. How can a weekend transport model be useful in general?

The interview finishes with asking whether the interviewee would like to receive results of the final report and if their are any remaining questions about how the interview will be used.

A.2. Interview municipality Den Bosch

The city of Den Bosch lies in the Province of Noord-Brabant and has around 160.000 inhabitants. The city is known for the 'Bossche bol' and it's historic city centre.

What do you do at the municipality?
As a policymaker, I focus on the mobility plans for the city Den Bosch. Since 2019 the municipality took the decision to outsource all the work regarding transport models to Goudappel. This work requires an expert within the municipality and that is costly. It is my job to check which things need to be calculated with a transport model, so that the outcome can be used for policy development. Next to this, I am also busy with the 'Mobiliteitsaanpak brede binnenstad'. This project focuses on new developments in the city centre and how the municipality can keep the city centre liveable and accessible.

As a municipality, you can have certain transportation goals such as: increasing the quality of bicycle lanes, developing areas with mixed land-use or making the city centre car-free. With these goals in mind:

1. What goals are applicable to the weekend?
Only recently has the municipality started to look at the weekend in detail. In a recent study into the transport system around the city centre, weekend days were incorporated into the study to predict the effect of new plans on the transport system. Currently Den Bosch has a ring road around the city centre but in the future, more houses will be build and there is not enough capacity on the ring road. That's why the ring road will be interrupted at a few places to change it's current functionality. Traffic on the ring road will then be diverted to roads further away from the city centre which are suited to handle more traffic. Subsequently, the city centre has to remain accessible and the municipality wants to create more space for cyclists and green spaces. Retailers were afraid that people would stop coming to the city centre if the accessibility by car is reduced so the impact on traffic flows was specifically studied for the weekend to be certain that the new plans wouldn't cause any new problems.

2. What would weekend-specific goals be?
I would then think about the study into the historic city centre, keeping the city centre accessible and liveable. Having adequate parking facilities that are used by visitors. The existing infrastructure should be utilised as smart as possible, or in a dynamic way possibly. Building an extra lane is expensive and there is practically no space to do this, so other alternatives are needed. It could be interesting to look at a different configuration of traffic lights in the weekend to facilitate peak traffic flows in a dynamic way. Next to this, as a municipality, car traffic should be facilitated as well as other modes. In some places there is not enough space

3. What are travel/traffic characteristics of your municipality or destinations that are important to know about when creating a transport model for the weekend?
In Den Bosch, there is a major flow of visitors in the weekend to the historic city centre. On a Saturday it can happen that people all go home at the same time and this leads to congestion which isn't there on workdays. This effect also varies per month, in January less people go shopping so this problem doesn't occur. In general, there is a difference in traffic flows between weekend and workdays, but this is mainly around the city centre.

Den Bosch also has a large event venue but it varies per event if this has a significant effect on the transport system. At some events, everyone comes by car, or visitors arrive at the same time. Sometimes this leads to congestion but this is something that depends on the event, not a structural phenomenon that happens in the weekend. There is also a smaller event venue where recently an event happend where everyone came by car. The roads around the venue didn't have enough capacity so this lead to congestion. If this event would have taken place on a workday, the same problem would have occurred.

4. How can a weekend transport model be useful in general?
I think a weekend transport model can help to understand how the infrastructure can be used in a smart way. The infrastructure is now optimized to facilitate traffic on workdays but maybe the weekend requires a different setup in terms of traffic lights or junction configuration. Only of course if there is a big difference between the weekend and workdays. People also complain less if they are delayed in traffic in the weekend when compared to workdays. This is also something that should be considered if the municipality wants to start developing plans for situations in the weekend. Having an understanding of a regular weekend day is interesting, but the additional value for policy development is limited. If there are no structural problems, then it doesn't make sense to adjust the infrastructure for example.

A.3. Interview Province of Overijssel

The Province of Overijssel is the fourth largest Province in the Netherlands but it's population density is low with around 1.2 million inhabitants. The Province has a couple of medium-sized to small cities such as Zwolle, Deventer or Enschede.

What do you do at the Province of Overijssel in your work?
A variety of different things regarding policy development for the Province of Overijssel. One of those things is to work together with Goudappel which has a transport model of the Province. Data and infor-

mation needs to be gathered for this model from different people and i work on applications or studies with the model. Extensive model studies are outsourced. Next to this, there are projects regarding logistics to gather data on freight movements or other data sources regarding traffic.

As a province, you can have certain transportation goals such as: increasing the quality of bicycle lanes, developing areas with mixed land-use or to keep the roads safe. With these goals in mind:

1. What goals are applicable to the weekend?
That's a difficult question, recreational traffic is relevant for the weekend but politically it's not seen as a goal for policy development. The topic doesn't get much attention because there is no specific policy development for the weekend or there is not enough data to do this.

2. What would weekend-specific goals be?
Most of the things I can think about are problems that on workdays in the transport network. These are things like traffic flow or traffic safety. Although, there is one specific problem which is that trucks are stopping near the border with Germany on special holidays. This is a very local problem in which the Province doesn't have any insights or it's difficult to estimate the effects of this. It would also be interesting to know in what way weekend traffic might be an issue in the future.

3. What are travel/traffic characteristics of your municipality or destinations that are important to know about when creating a transport model for the weekend?
There aren't any specific places which stand out in the Province. One thing is that the roads between cities are busy or locations such as Ikea's have a big attraction value. Some regions of the Province might also deal with more leisure traffic but this is not a structural issue. Although there are a lot of campsites in the Province, weekends are generally not busier in the summer period.

4. How can a weekend transport model be useful in general?
It would be more interesting to know what the major differences are and if these should be taken into account for policy development. Next to this, a transport model could be usefull to better measure the impact of traffic on the environment. The current method uses a weekday transport model to calculate traffic flows on weekend days. Specific weekend travel behaviour is thus not present in these calculations and a weekend transport model could thus improve this. Lastly municipalities look at their transport system in a different way, so they might want to use a different kind of transport model as they look at a different spatial level.

A.4. Interview municipality of Zwolle

The city of Zwolle lies in the Province of Overijssel and has 130.000 inhabitants.

What do you do at the municipality?
I work as an advisor for mobility projects for the municipality of Zwolle. A lot of that work is focused around the city centre. The municipality is working towards a new transport system in which the inner ring road will be transformed into a cycling route and car traffic is diverted to the outer ring road of the city. Next to that, the city wants to develop mobility hubs where people can park their car and take a different mode of transport to the city centre.

As a municipality, you can have certain transportation goals such as: increasing the quality of bicycle lanes, developing areas with mixed land-use or making the city centre car-free. With these goals in mind…

1. What goals are applicable to the weekend?
Difficult to say, other colleagues look more at the entire transport network of the city so they might have a different opinion on this but the municipality hasn't really considered the weekend in the past. Still, the weekend is interesting as traffic intensities in the weekend are not substantially lower than on workdays.

2. What would weekend-specific goals be?
Some peak traffic flows are observed on Saturdays around the city centre when people that went shopping leave the city. On Sundays, traffic is characterised by people going to church. Weekend-specific goals are good to think about, especially because the municipality is adopting a new system which has a reduction in capacity on some places. It's possible that weekend traffic requires different

configurations for traffic lights, to handle peak traffic. It would be interesting to see what insights a weekend transport model can bring and how this can influence the current decision-making process for the municipality. Alternatively, such a model could be used to analyse what parking facilities will fill up quickly or to test solutions to divide the traffic over different parking facilities.

3. What are travel/traffic characteristics of your municipality or destinations that are important to know about when creating a transport model for the weekend?
Zwolle has different locations where weekend traffic might go to. The northside of the city has a lot of Hardware stores. Just outside the city, there is an IKEA and the Intratuin. Next to that, there is a concentration of furniture shops and Zwolle used to have an event location. It depended on the event if this had consequences for the transport network.

4. How can a weekend transport model be useful in general?
A real purpose is not recognized by the municipality of Zwolle but such a model can bring interesting insights. If it is available, it would be interesting to see some outcomes.

A.5. Interview Province of Noord-Brabant

The Province of Noord-Brabant has the third most inhabitants with around 2.5 million inhabitants. The transport system of the Province sees a lot of freight traffic between neighbouring countries and the major ports. On the recreational side, there is a large amusement park and attractive cities to visit.

What do you do at the Province?
In my work at the Province of Noord-Brabant I oversee the development and use of transport models and policy development around traffic safety. This includes working with municipalities in the Province on different projects.

1. What are travel/traffic characteristics of your municipality or destinations that are important to know about when creating a transport model for the weekend?
Some provincial roads see a lot of freight traffic, this is different in the weekend so freight traffic has a significant effect on traffic flow in the Province.

2. How can a weekend transport model be useful in general?
For the Province of Noord-Brabant, this is not interesting. The road network is robust enough to handle average weekend days. Except for some particular days when large events take place. Therefore it doesn’t seem sensible to develop and use a model for the weekend as there are no particular problems in the weekend. The destinations to which people travel might be different, so it’s possible that a weekend model is more interesting for municipalities.

B

Appendix B: Surface area analysis

In this appendix, an analysis of the ”Basisregistratie Adres Gegevens’ (BAG) dataset, which translates to ’Basic registration of adress data’, is presented. The BAG data is publicly available via the Cadastre or land registry which is a public authority that registers which plots of land belong to whom (Kadaster, 2025). An analysis of the BAG data was done in this study to try and include spatial variables which can act as trip generation variables for leisure-related trip purposes. This is done, as it was found in Chapter 3 that trip generation models could be improved by using different data sources with a higher quality. Additionally, the findings of this appendix are used in Chapter 6 to create an adaptation for a Saturday transport model.

This appendix is structured in the following way, first a description of the BAG data is given. Then an explanation is given on the downsides of a spatial variable that is currently used. After that, an analysis is done which checks whether the BAG data is useful for these trip attraction variables. Finally, additional results are presented which show how the variables function within the transport model.

B.1. BAG data description

The BAG data contains information on all the registered addresses in the Netherlands. Per address, data is available on the registered use of the building, the surface area of the address and the construction year of the building. If a building contains multiple addresses, like in an apartment building, data is available per address. The BAG data only contains information on the surface area of the building itself, but not on the surrounding plot of land. The BAG data is updated by municipalities so it’s possible that the quality of the data can differ. Next to that, the registered use of a building in the BAG can differ from the actual use of the building.

An example of the BAG data can be seen in figure B.1, which is a screenshot of the BAG data viewer with the Saint John’s Cathedral of Den Bosch in the middle. In the figure, all the buildings are highlighted which have the building use ’Gathering’. This can be buildings such as a church, restaurants, theatres or a hotel which fall under this building use. The registered surface area for the Saint John’s Cathedral here is around 5000 m^2.

Eleven building uses are defined in the BAG data, based on building regulations in the Netherlands. An overview of these can be seen in table B.1. Next to the building uses, the type of buildings that can correspond to such a building use are shown. The building types are not included in the BAG data but they were derived from the data by comparing the BAG data to Google Maps. The result of this investigation is that there are a lot of building types under each building use. Especially for a building use such as Gathering, the types of buildings are very diverse. A short investigation of all the building uses in the BAG viewer showed that not all building uses are intuitive. For example, a building that falls under Healthcare is actually an office of a healthcare institute. The use of the building could thus suit better under offices. In some cases, an address can also have two building uses. For example if a house has an office or shop on the ground floor. The address has the building uses: Living and Shopping. In the current analysis, an address with multiple building uses was not included as this was a

Figure B.1: BAG data viewer

small subset of the data and it is not clear what the respective surface area is of both building uses. To conclude, the BAG data contains a lot of information, but the mentioned characteristics are important for the rest of this analysis.

Table B.1: Building uses and corresponding types in the BAG data

Building use	Type of buildings
Living	Homes
Gathering	Churches, libraries, public administration buildings, theaters, sport stadiums and more
Detention	Prisons, etc..
Healthcare	Hospitals, doctor's offices, dentists, and more
Industrial	Factories, utility buildings
Office	Offices,
Lodging	Campsites, hotels, and more.
Educational	Schools, universities, and more.
Sport	Sportclub buildings, gyms, etc..
Shopping	Shops, department stores,
Other building use	Other buildings uses not mentioned here.

B.2. Matching building use to trip purpose

In model version A, a set of variables is used in the trip generation model to predict some aggregate travel behaviour per trip purposes. For some trip purposes, the assumption is made that the trip attraction can be explained by the number of inhabitants in a zone, as can be seen in table B.2. Ideally this would be a spatial variable like the number of retail jobs in a zone, but for some trip purposes, such a variable is not known yet.

Next to this, it was found by the company that the current variable to predict the number of shopping trips towards a zone, is sometimes not able to estimate this correctly. This can be caused by the variable itself which is based on the number of retail jobs in a zone. This number can range from 1 to 100+ jobs per zone, while the number of trips that need to be divided between zones can range from 100 to 2000+. This is not proportional to the number of retail jobs, making it difficult for the model to correctly portray the difference between 5 or 6 jobs in a zone. Additionally, there can also be a mismatch in the number of visitors that go to a shop and the number of retail jobs. For example, two shops can have the same number of retail jobs, while the other shop is larger or more popular. The surface area of a shop could solve this problem but it neglects that some shops attract more visitors than others. An ideal solution would be to combine the surface area of shops with visitor counts to come to an attraction value per square meter per type of shop, as was discussed in section 3.4. Still, the BAG data can present a first step in the right direction. It is thus hypothesised that a variable based on the surface area of shops in a zone can better predict the relative differences in trip attraction.

Table B.2: Variables in trip generation step of Model A

Purpose	Production	Attraction
Work	Working population	Number of jobs
Shopping	Inhabitants 15+	Number of retail jobs
Socrec	Inhabitants 15+	Inhabitants
Sport	Inhabitants 15+	Inhabitants
Visits	Inhabitants 15+	Inhabitants
Drop off/pick up	Inhabitants 15+	Inhabitants
Other	Inhabitants 15+	Inhabitants

For both these problems, the BAG data can be a solution but before that, it has to be determined which type of building uses can correspond to trip purposes in the trip generation model. After an analysis of the BAG data itself, it was found that a few building uses can match to a trip purpose. This was found for the trip purposes Shopping, Socrec and Sport. A description of this analysis is found in the following paragraphs.

The remaining trip purposes could not be matched to a building use. For the trip purpose Visits, it seems logical that the number of inhabitants per zone can predict the trip attraction as these are trips that have a destination at someone else's home. Drop off/pick up trips have a set of possible destinations that is too broad too be matched to the BAG data. This can be trips to a train station, parcel lockers or someone else's home. A train station is a destination that could be included in some way but it's not known what percentage of drop off/pick up trips goes to a train station. Therefore, the current variable is kept for drop off/pick up trips. This is also done for 'Other trips', which isn't characterized by a set of destinations. The trip purpose Work already has a spatial attraction variable, so to keep the changes to the model to a minimum, this variable is kept the same.

Shopping
First of all, the building use shopping can be used for the trip purpose shopping, as it was identified that this variable can be improved and the building type matches the trip purpose. A flaw in this method was described in the previous paragraph, as it might be better to use an attraction value per square meter per type of shop, but the BAG data doesn't differentiate between types of shops.

In figure B.2, point data of the BAG which is filtered for the building use shopping is shown for an area around Den Bosch. The locations of the point data correspond to city or village centres where shops are expected.

Social-recreational
Secondly, the building type 'gathering' or 'lodging' can be matched to the trip purpose SocRec. The building type 'gathering' contains a lot of social-recreational destinations which could correctly predict the corresponding destinations for this trip purpose. The building type 'lodging', could also match this destination, as a lot of campsites or recreational accommodations are included in this variable. Figure B.3 shows where all the buildings with building use 'Gathering', are located. These are a lot of destinations both in city's and villages and in rural areas. This could possibly reflect the multitude of social-recreational destinations that exist. Figure B.4 shows all the buildings with building use 'Lodging'. It can be seen that campsites with bungalows have a lot of points in certain zones but there are also lodging accommodations in the city of Den Bosch.

Sport
Thirdly, the building type Sport, could match the purpose sport. A likely flaw of using the BAG data for this, is that only the surface area of the building is included but not the surrounding area. This would make the number of sports fields near a sports building irrelevant, while this could be an important measure to realistically portray the attracted number of trips. However, if only the building itself is considered, this would make it more comparable to a gym or smaller sports accommodations, because

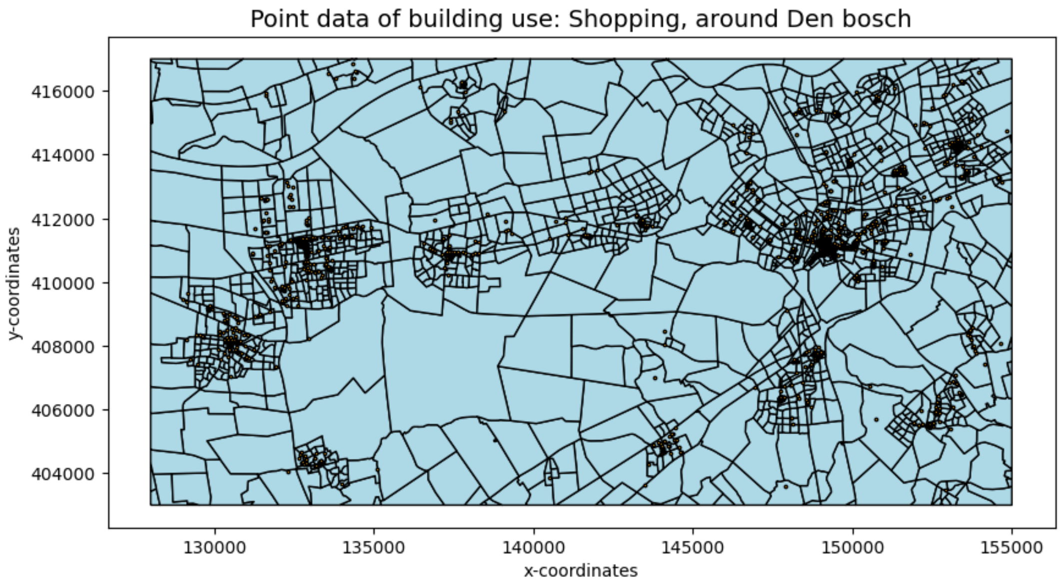

Figure B.2: BAG data of building use: Shopping

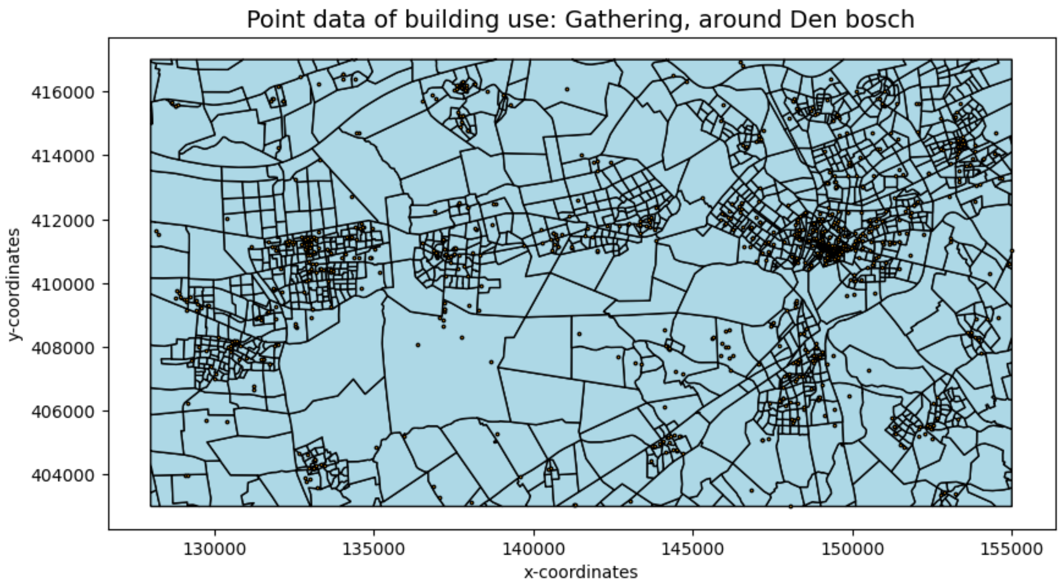

Figure B.3: BAG data of building use: Gathering

a sports field can have a large surface area. The number of players per square meter of sports field is of course not comparable to the number of people in a gym per square meter. Excluding the sports field would thus reduce these large differences. Additionally, the trip purpose sport also predicts hobby trips. The building use sport does not include the possible destinations that belong to hobby trips, so that would be a big assumption to make. Figure B.5 shows the point data of sport buildings in the area of Den Bosch.

B.3. Analysis of surface area.

The point data in the BAG dataset was aggregated to the zonal level of the BBMA model, so that the data can be used as a variable in the trip generation model. Before that, an analysis is performed on the resulting variable to verify if the resulting variable can be used in the model.

First of all, figure B.6 shows the variable that is currently used to estimate the relative differences in

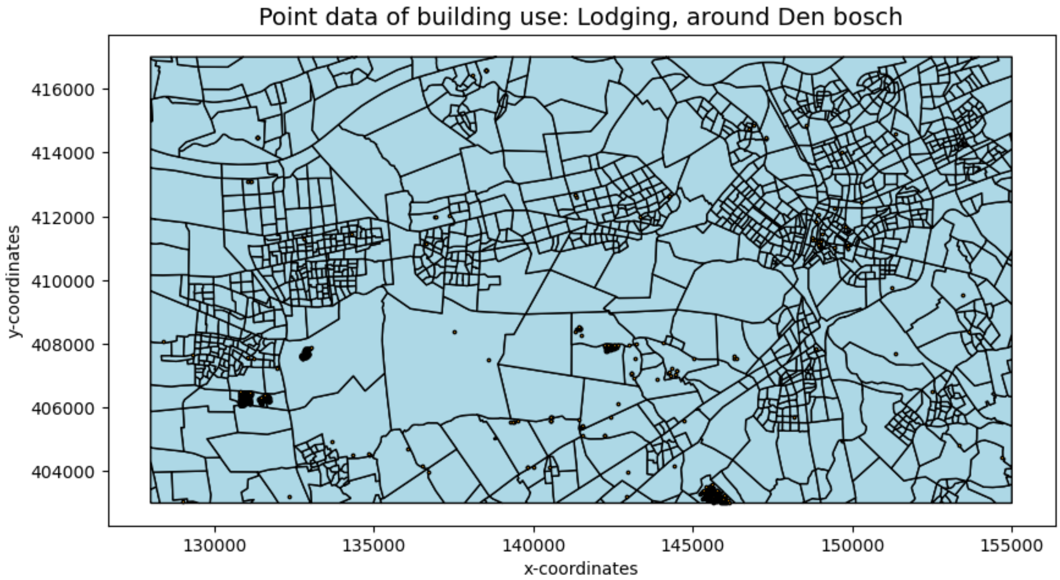

Figure B.4: BAG data of building use: Lodging

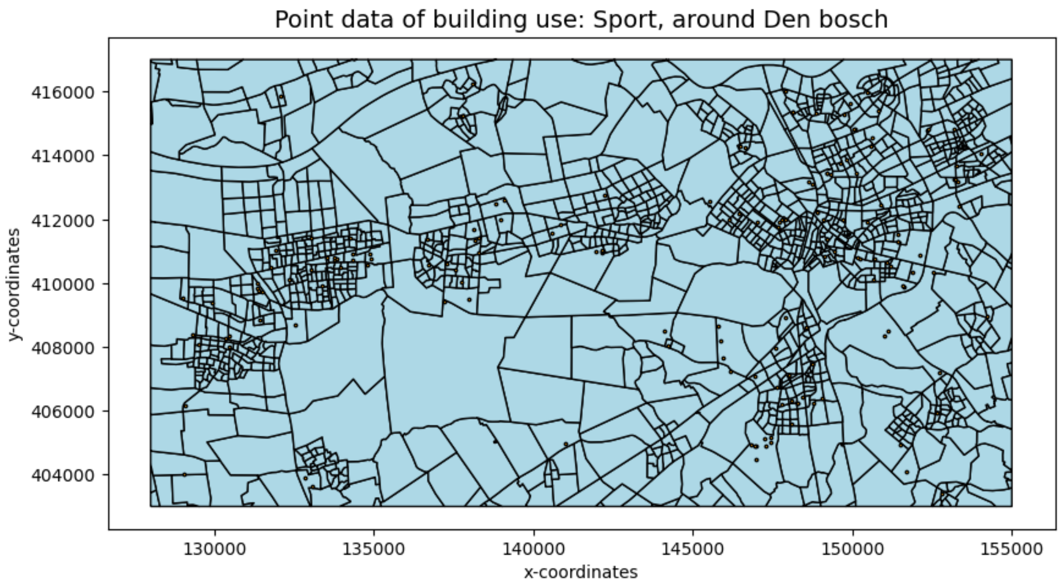

Figure B.5: BAG data of building use: Sport

trip attraction for shopping trips. This is plotted on the zonal level of the BBMA model with a colour scale. Note that the order of magnitude can change in different figures. When this figure is compared to figure B.7, which is based on the BAG data. It is interesting to see that there are more zones in figure B.6 that have retail jobs in rural areas than in figure B.7. This is a peculiar difference that can already explain the mismatch that the company sees in the number of shopping trips that go to a zone. Furthermore, in figure B.7 it is immediately clear that the city centre of Den Bosch has more shops than other neighbourhoods around it, reflected by the dark orange colour in the figure. This difference is not clear from figure B.6, while it is expected that there are more shops in the city centre. Next to the city centre of Den bosch, shopping centers in neighbouring villages are easily identifiable. Using the surface area of shops thus seems as a good variable to predict the number of shopping trips that go to an area.

The trip purpose Socrec can possibly be explained by two variables from the BAG data. This can be

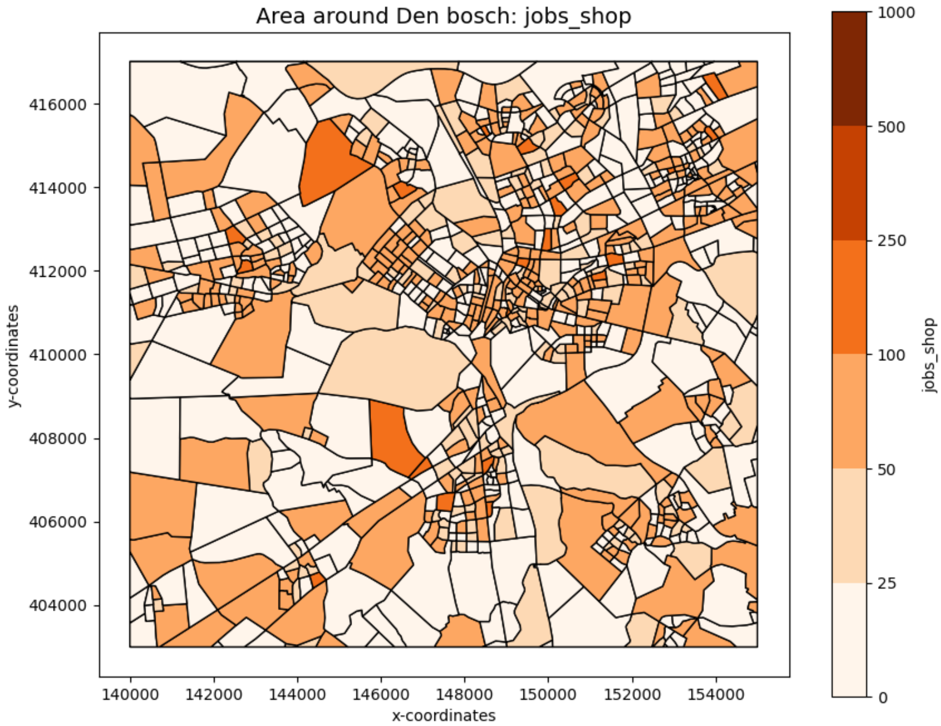

Figure B.6: Number of retail jobs per zone

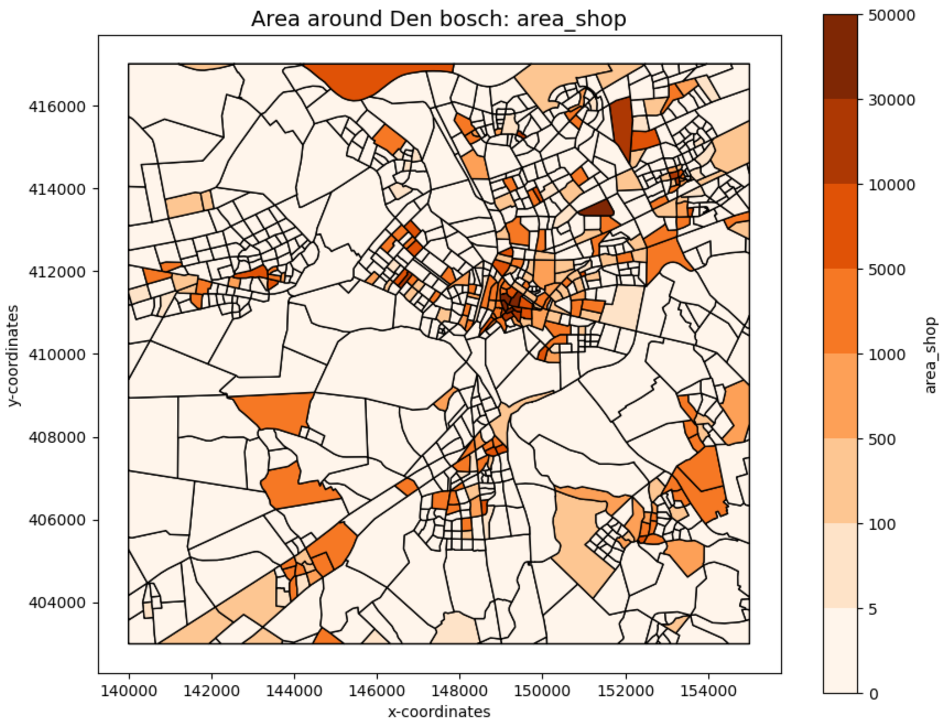

Figure B.7: Surface area of shops per zone

the surface area of 'Gathering' buildings in figure B.8 or 'Lodging' buildings, shown in figure B.9. The first figure shows that there are a lot of zones with social-recreational buildings, but there are also explainable differences, such as that zones in the city centre have more social-recreational buildings. The second figure shows that lodging accommodations are mainly outside the city. In a comparison between the two variables, the total surface area was compared, because it is important that the variable showcases the correct relative differences. Combining the two variables would mean that an assumption needs to be made about the share of recreational trip that stems from a hotel or campsite on a Saturday. It's not possible to derive this from the ODiN data and the question is whether trips to and from a campsite should automatically be classified as social-recreational, or that such a location functions as a temporary home. The latter is probably more true. Next to this, the total surface area of a campsite would attract a large share of the social-recreational trips. This will probably overestimate the number of trips that go to a campsite for social-recreational purposes so therefore only the building use 'Gathering' is used for the trip purpose Socrec.

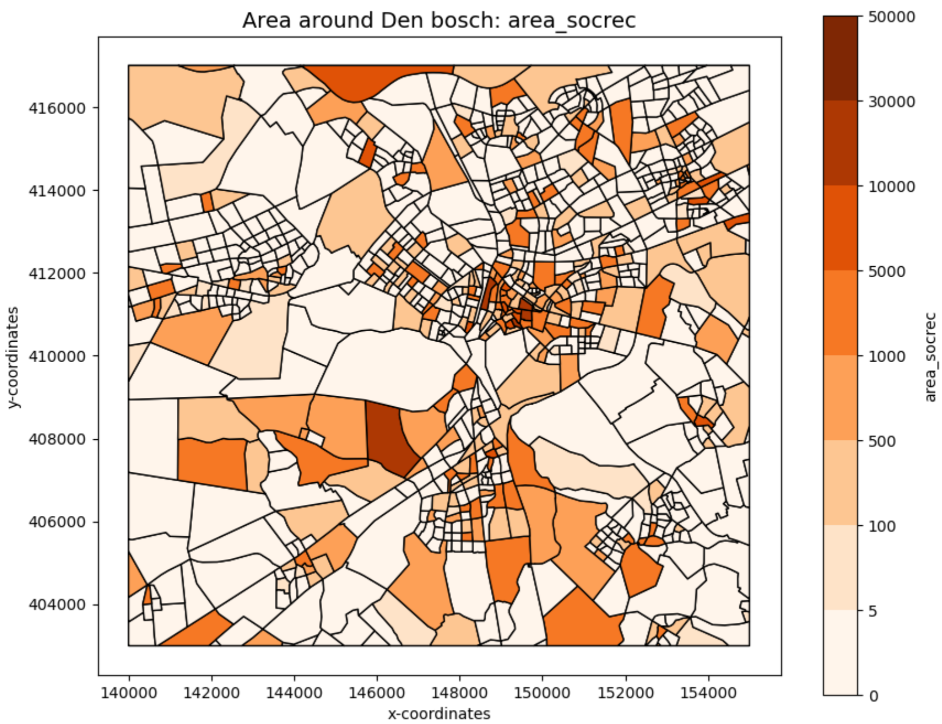

Figure B.8: Surface area of SocRec buildings per zone

Figure B.10 shows the relative differences between zones for the building use sport. Interestingly, most of the coloured zones lie outside or on the edge of the built environment. This is a logical location for sports fields but a gym can also be located in a city. When the city of Den Bosch is observed, it would be logical that there are more zones with a sports building. A further analysis of what kind of buildings are classified with the building use sport can clarify this but for now this variable can be used for the trip purpose sport.

The result of this analysis is that three building uses are used for the following trip purposes, namely, Shopping, Socrec and Sport. These changes are summarized in table B.3.

Table B.3: Changed variables in trip generation step of Model B

Purpose	Production	Attraction
Shopping	Inhabitants 15+	Surface area of retail shops*
Socrec	Inhabitants 15+	Surface area of recreational buildings*
Sport	Inhabitants 15+	Surface area of sport buildings*

B.4. Results

The majority of the results of this adaptation can be found in Chapter 7 but a few specific results are highlighted here. A conclusion from the local travel demand analysis was that the variable that is used in

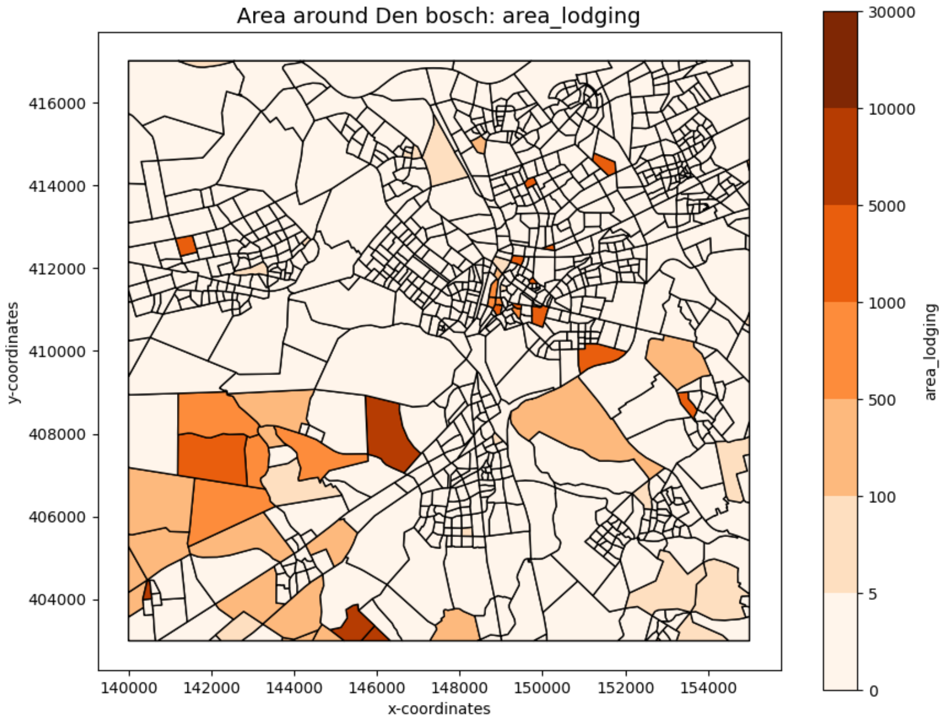

Figure B.9: Surface area of lodging buildings per zone

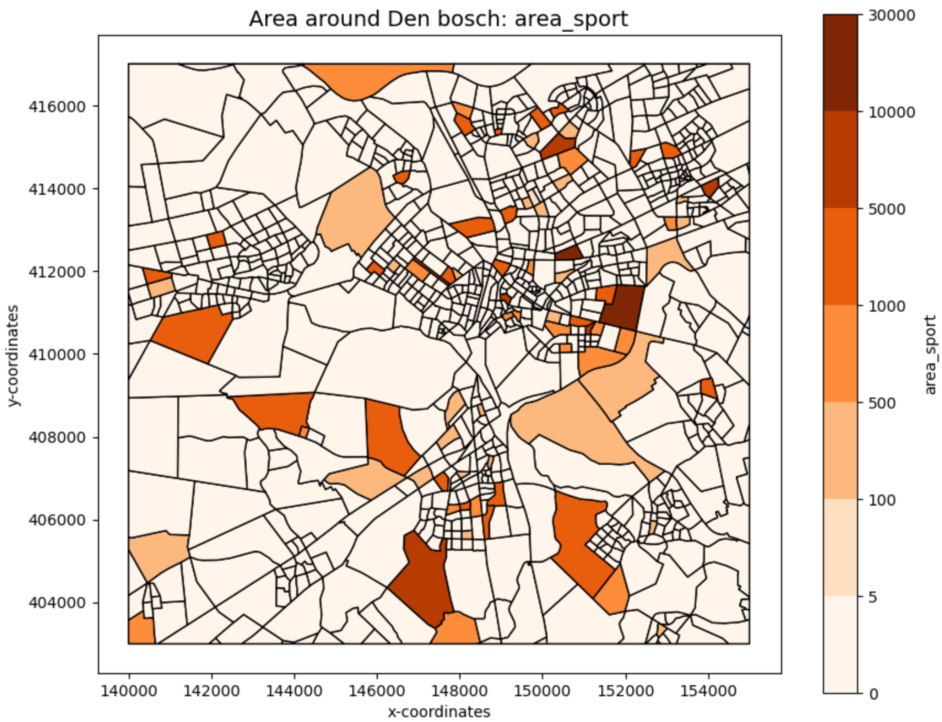

Figure B.10: Surface area of sport buildings per zone

the trip generation model largely influences the trip purpose distribution in a zone. From this, model B2 seemed to overestimate Shopping trips, underestimate Socrec trips and incorrectly predict the number of Sport trips in comparison with model A2. The following figures: B.11, B.12, B.13, present this by showing the difference in traffic intensity for the municipality of Den Bosch. A red colour indicates that model B2 has a larger intensity than model A2, and a green colour indicates the opposite. The intensity is based on an All-Or-Nothing traffic assignment method. This means that all traffic is assigned on the shortest route, irrespective of the capacity on the roads.

Figure B.11 shows that the majority of the shopping trips is attracted to the city centre of Den Bosch as there is the largest difference in traffic intensity. It's interesting to note that this difference can be seen on the highways so it is possible that a lot of trips are coming from outside Den Bosch to go shopping.

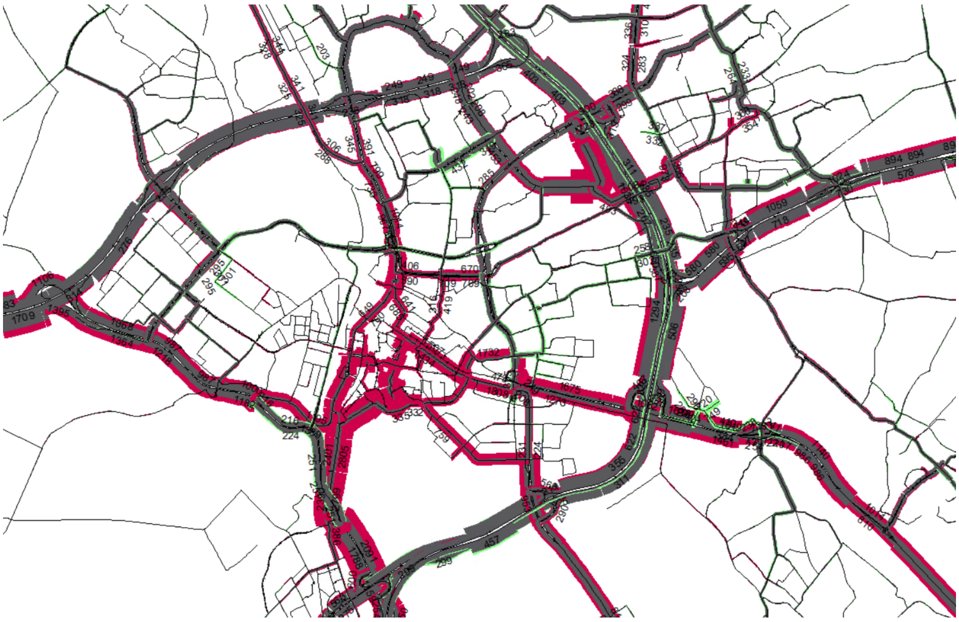

Figure B.11: Difference in intensities for the trip purpose Shopping between model A2 and B2. *Red: A2 < B2, Green: A2 > B2*

The difference in Socrec trips isn't that large but there is again a large difference of trips towards the city centre of Den Bosch in model B2. In model A2, the trip generation of Socrec trips was based on the number of inhabitants so it's logical that the trips are more concentrated in model B2. Additionally, a reverse difference is visible on the highways, meaning that most Socrec trips come from the vicinity of Den bosch.

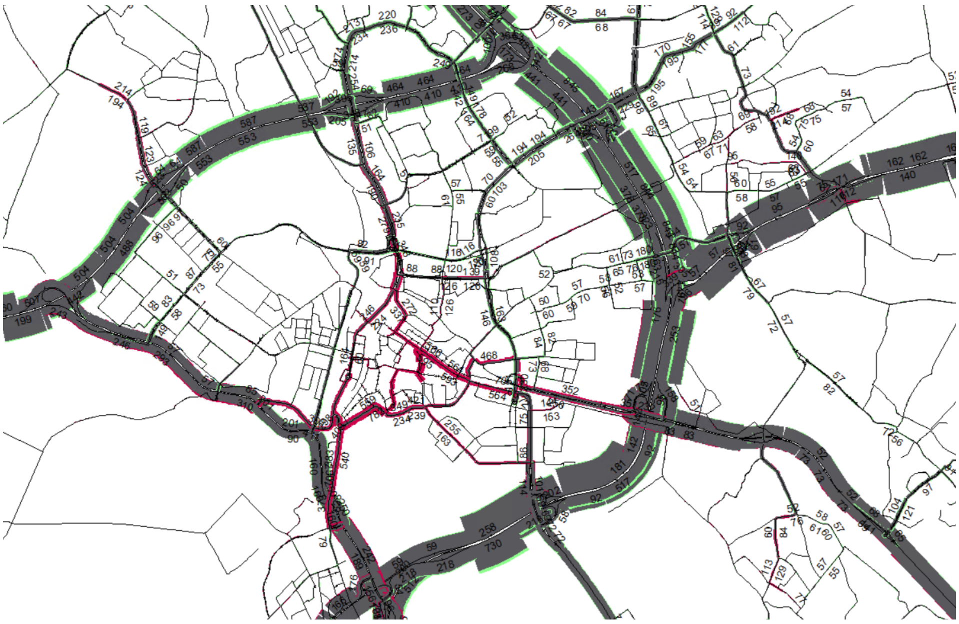

Figure B.12: Difference in intensities for the trip purpose Socrec between model A2 and B2. *Red: A2 < B2, Green: A2 > B2*

The difference in Sport trips show large differences on the highway than was seen with the Shopping trips. This is peculiar as it would be expected that sport trips are made in the vicinity of Den Bosch. It turned out that the new variable couldn't correctly predict the number of trips going to Den Bosch. This is highlighted by table B.4 which show the trip production and trip attraction for Den Bosch and Vught itself. For Socrec trips, the production and attraction is somewhat equal in both municipalities but this isn't the case for Sport trips. There it can be seen that there is a large difference between the number of trips originating and arriving in the municipalities. This is then an input to the trip distribution step of the model, which causes the large traffic intensities on the highways, as Sport trips have to be made towards another municipality.

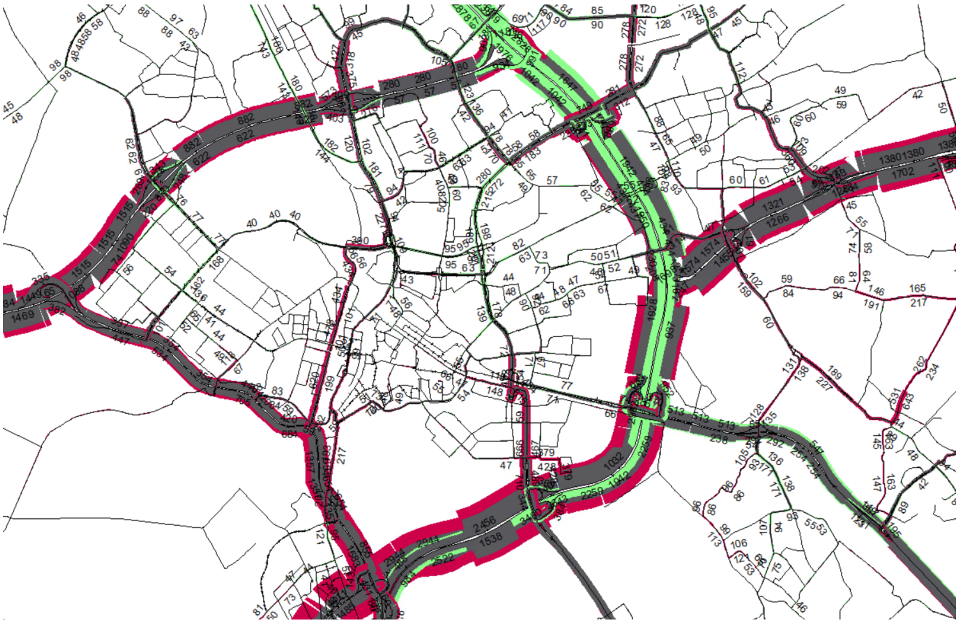

Figure B.13: Difference in intensities for the trip purpose Sport between model A2 and B2. *Red: A2 < B2, Green: A2 > B2*

Another flaw in this method was that the new variable could only be estimated for the areas in the Netherlands. This resulted in incorrect traffic intensities going to Belgium for Socrec and Sport trips which also had an affect on traffic intensities in the Netherlands. A solution for this could be to equal trip production to trip attraction and by increasing the share of intrazonal trips. In this way, the model won't try to distribute trips from Belgium to destinations farther away than the border region. This problem didn't appear for the Shopping trips, as the variable in model A2 could be used in the areas outside of the Netherlands.

Table B.4: Total trip generation in Den Bosch and Vught for the purpose Socrec and Sport

	Home-Socrec	Socrec-Home	Home-Sport	Sport-Home
Trip production Den Bosch	14295	14136	17505	7278
Trip attraction Den Bosch	16580	13508	8407	15262
Trip production Vught	3698	3218	4295	7426
Trip attraction Vught	3600	3289	8798	3695

To conclude, the variable for Sport trips in model B2 is therefore not a correct variable to predict the number of sport trips, as it causes large differences between municipalities which are not realistic. The Shopping and Socrec variables highlight the findings from the results Chapter and these could be suited for further use in a transport model.

C

Appendix C: Additional figures from the data analysis

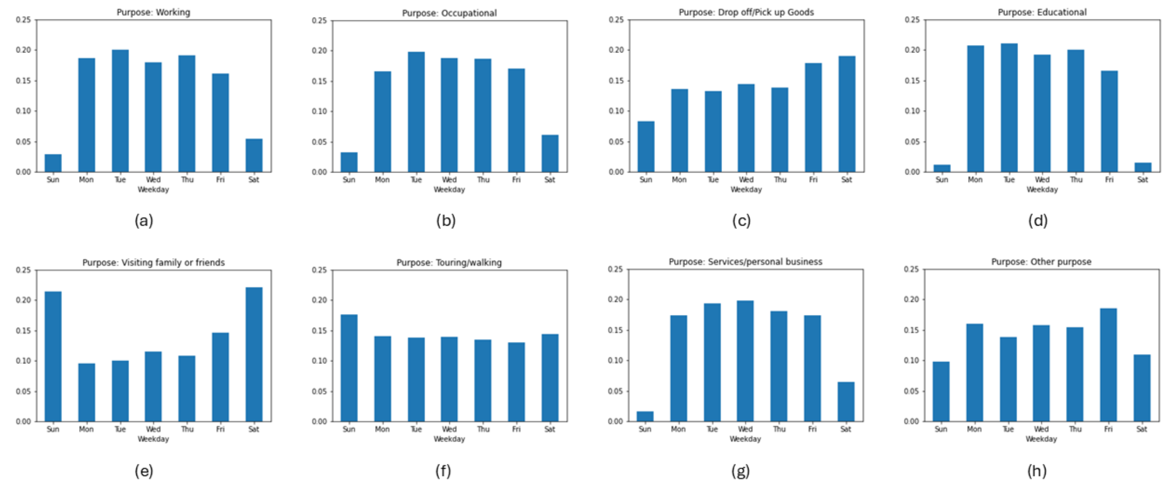

Figure C.1: Percentages of trips made for different ODiN trip purposes over all weekdays

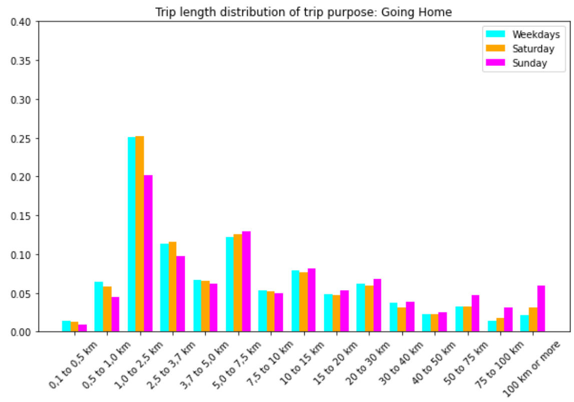

Figure C.2: ODiN trip purpose: Going Home

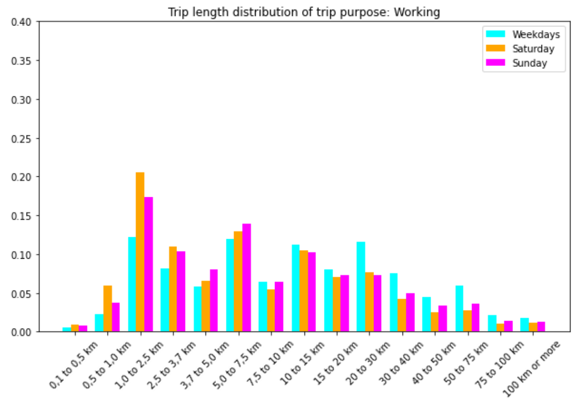

Figure C.3: ODiN trip purpose: Working

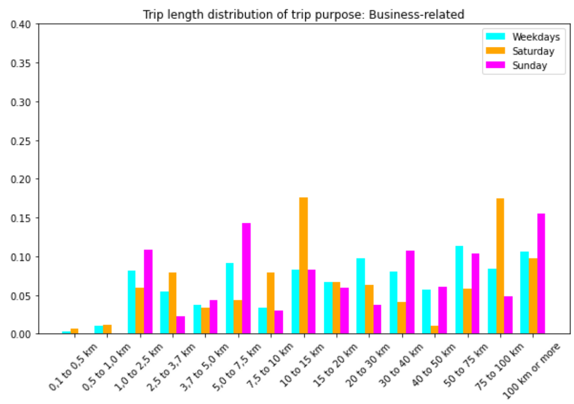

Figure C.4: ODiN trip purpose: Business

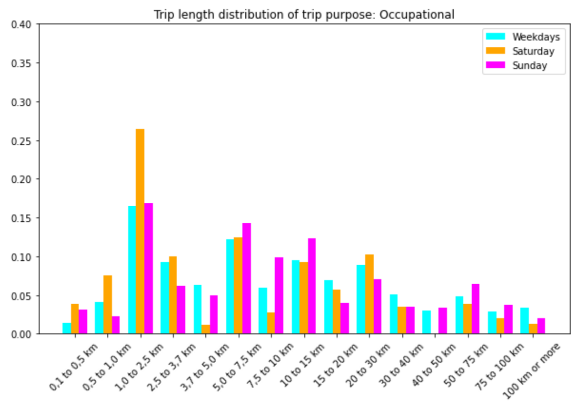

Figure C.5: ODiN trip purpose: Occupational

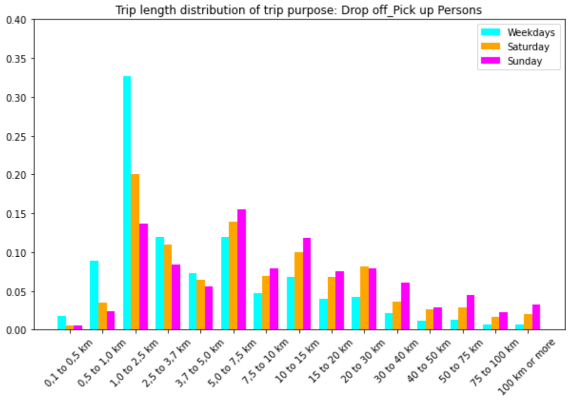

Figure C.6: ODiN trip purpose: Drop off/pick up Persons

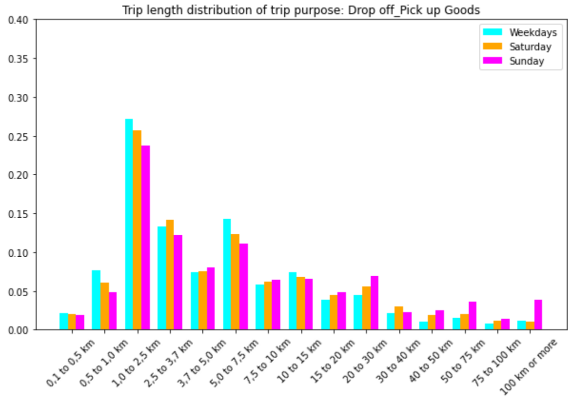

Figure C.7: ODiN trip purpose: Drop off/pick up Goods

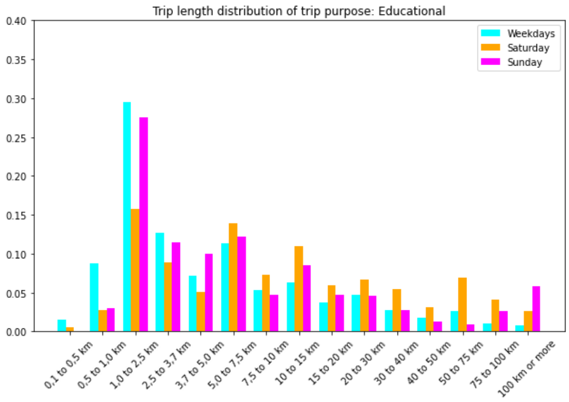

Figure C.8: ODiN trip purpose: Educational

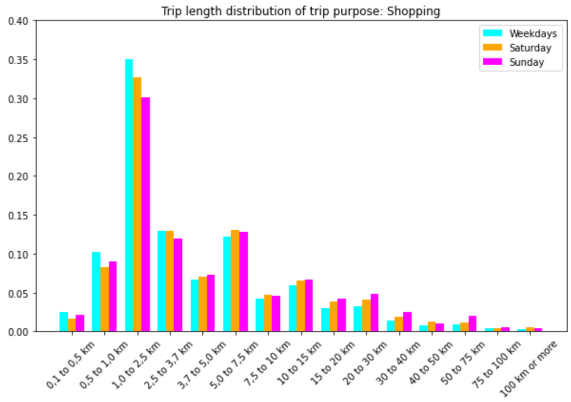

Figure C.9: ODiN trip purpose: Shopping

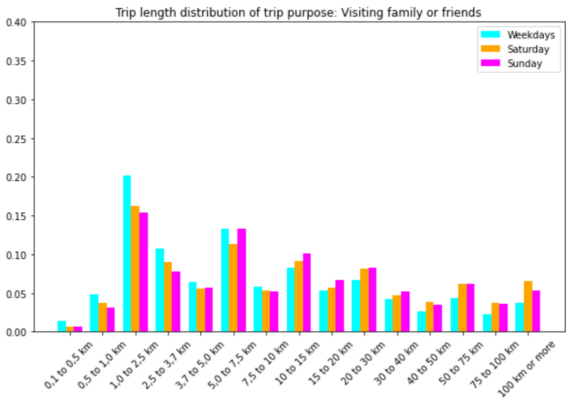

Figure C.10: ODiN trip purpose: Visiting family or friends

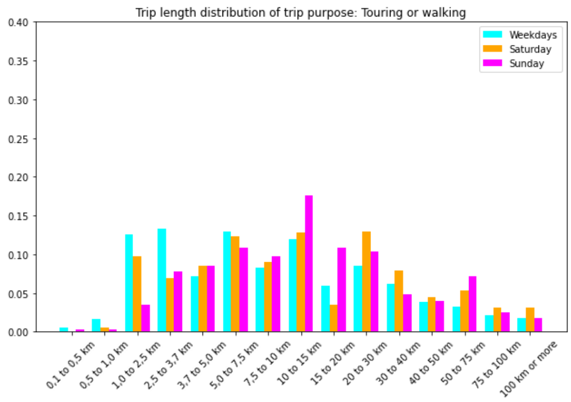

Figure C.11: ODiN trip purpose: Touring or walking

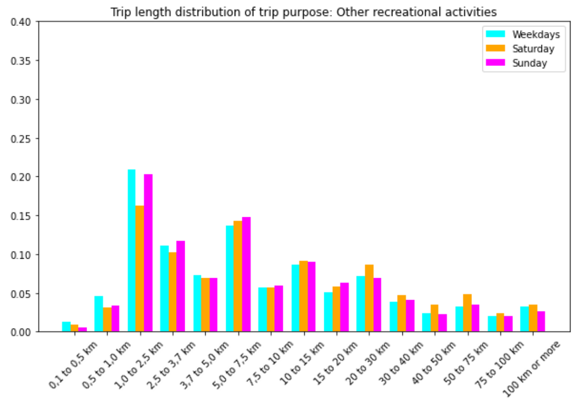

Figure C.12: ODiN trip purpose: Other recreational activities

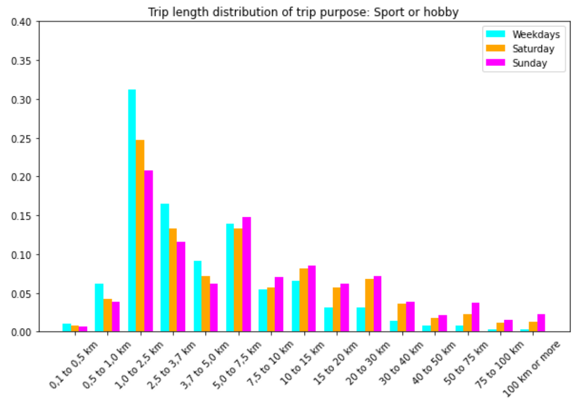

Figure C.13: ODiN trip purpose: Sport or Hobby

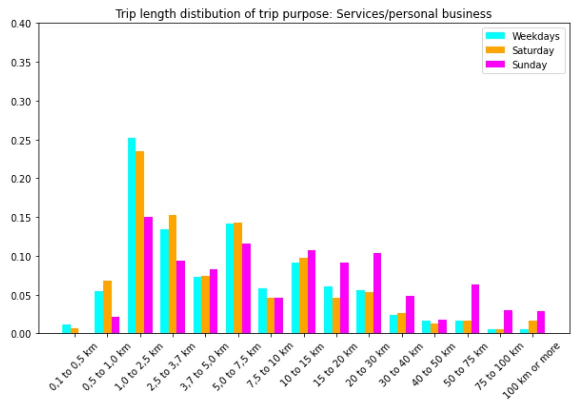

Figure C.14: ODiN trip purpose: Services

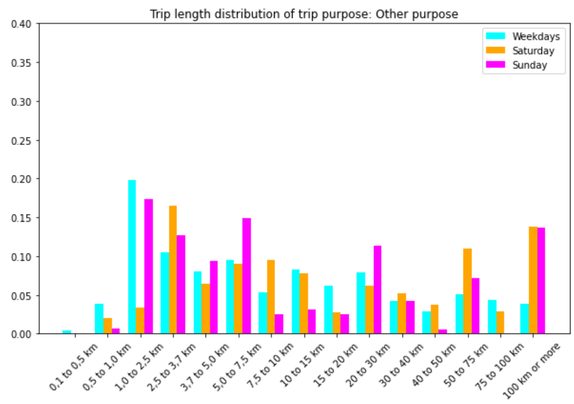

Figure C.15: ODiN trip purpose: Other purpose

D

Appendix D: Parameter estimation outcome and trip length distribution plots

Table D.1: α, β parameters from the old workday model based on OViN data

	α_{Car}	α_{PT}	α_{Bike}	β_{Car}	β_{PT}	β_{Bike}
Work CA	85,7	1,0	15,4	-0,356	-0,235	-0,366
Work CNA	12,2	1,0	12,6	-0,358	-0,227	-0,365
Business CA	47,1	1,0	5,5	-0,404	-0,294	-0,408
Business CNA	13,7	1,0	7,2	-0,382	-0,262	-0,403
Shopping CA	7,8	1,0	2,8	-0,725	-0,556	-0,856
Shopping CNA	1,0	1,1	1,3	-0,710	-0,547	-0,880
Education CA	2,6	1,7	1,0	-0,540	-0,368	-0,425
Education CNA	1,0	6,5	4,3	-0,565	-0,370	-0,427
Other CA	78,2	1,0	33,2	-0,476	-0,284	-0,565
Other CNA	14,9	1,0	20,6	-0,475	-0,277	-0,571

Table D.2: α, β parameters and statistics for mode Car in Saturday model A

Purpose	α_{A1}	α_{A2}	β_{A1}	β_{A2}	Cor A1	Cor A2	Diff RMSE (%)
Work CA	70,95	378,59	-0,401	-0,430	0,608	0,602	-2,9
Work CNA	3,97	2,49	-0,375	-0,417	0,745	0,547	3,0
Shopping CA	3827,19	2764,19	-0,542	-0,622	0,930	0,998	-58,5
Shopping CNA	251,94	161,39	-0,510	-0,594	0,878	0,978	-32,8
SocRec CA	24,34	20,12	-0,366	-0,373	0,353	0,894	-47,8
SocRec CNA	33,31	33,82	-0,359	-0,374	0,574	0,733	-16,4
Sport CA	119,14	114,21	-0,401	-0,412	0,642	0,923	-38,4
Sport CNA	33,58	24,45	-0,387	-0,406	0,895	0,981	-40,1
Visits CA	13838,90	15258,94	-0,350	-0,344	0,597	0,606	-4,8
Visits CNA	387,57	348,57	-0,326	-0,314	0,744	0,511	12,7
Pick up/drop off CA	250,11	137,85	-0,447	-0,463	0,890	0,950	-11,9
Pick up/drop off CNA	1440,99	1252,33	-0,483	-0,515	0,928	0,964	-11,8
Other CA	465,21	300,86	-0,397	-0,406	0,904	0,943	-9,1
Other CNA	131,44	158,53	-0,374	-0,389	0,639	0,864	-25,8

Table D.3: α, β parameters and statistics for mode PT in Saturday model A

Purpose	α_{A1}	α_{A2}	β_{A1}	β_{A2}	Cor A1	Cor A2	Diff RMSE (%)
Work CA	1,00	1,00	-0,349	-0,285	0,211	0,564	-34,6
Work CNA	1,00	1,00	-0,323	-0,373	0,110	0,497	-25,5
Shopping CA	1,00	1,00	-0,203	-0,242	0,771	0,774	-0,1
Shopping CNA	1,00	1,00	-0,246	-0,291	0,134	0,138	0,9
Socrec CA	1,00	1,00	-0,235	-0,237	0,498	0,323	10,6
Socrec CNA	1,00	1,00	-0,188	-0,188	0,699	0,821	-15,6
Sport CA	1,00	1,00	-0,282	-0,277	0,008	0,257	0,1
Sport CNA	1,00	1,00	-0,257	-0,268	0,047	0,008	-1,0
Visits CA	1,00	1,00	-0,067	-0,058	0,955	0,950	2,6
Visits CNA	1,00	1,00	-0,083	-0,077	0,837	0,851	-2,6
Pick up/drop off CA	1,00	1,00	-0,294	-0,314	0,058	0,128	-3,9
Pick up/drop off CNA	1,00	1,00	-0,179	-0,190	0,980	0,980	-0,1
Other CA	1,00	1,00	-0,181	-0,196	0,764	0,782	-5,3
Other CNA	1,00	1,00	-0,152	-0,147	0,813	0,828	-2,0

Table D.4: α, β parameters and statistics for mode Bicycle in Saturday model A

Purpose	α_{A1}	α_{A2}	β_{A1}	β_{A2}	Cor A1	Cor A2	Diff RMSE (%)
Work CA	54,57	69,76	-0,452	-0,471	0,963	0,974	6,4
Work CNA	36,39	4,93	-0,517	-0,594	0,997	0,988	40,0
Shopping CA	2514,28	688,97	-0,544	-0,654	0,984	0,999	-44,7
Shopping CNA	881,88	224,23	-0,634	-0,872	0,997	0,999	-23,3
Socrec CA	30,60	12,66	-0,408	-0,373	0,793	0,998	-79,6
Socrec CNA	89,34	47,81	-0,504	-0,592	0,997	0,996	-1,7
Sport CA	246,05	112,21	-0,506	-0,545	0,944	0,999	-73,7
Sport CNA	186,92	71,53	-0,503	-0,586	0,958	0,999	-65,3
Visits CA	18214,95	12535,01	-0,467	-0,506	0,981	0,997	3,9
Visits CNA	1321,25	662,12	-0,437	-0,401	0,891	0,999	-82,2
Pick up/drop off CA	163,92	40,64	-0,650	-0,839	0,999	0,993	62,1
Pick up/drop off CNA	906,24	329,98	-0,503	-0,545	0,992	0,999	-23,3
Other CA	303,93	108,49	-0,464	-0,510	0,947	1,000	-8,4
Other CNA	196,96	122,73	-0,452	-0,483	0,991	0,992	14,1

Table D.5: α, β parameters and statistics for mode Car in Workday model O

Purpose	α_{O1}	α_{O2}	β_{O1}	β_{O2}	Cor O1	Cor O2	Diff RMSE (%)
Work CA	10387,60	6598,54	-0,359	-0,350	0,782	0,651	-0,1
Work CNA	626,45	81,43	-0,343	-0,335	0,809	0,668	-0,7
Business CA	223,26	534,99	-0,458	-0,438	0,706	0,793	-14,6
Business CNA	185,82	403,13	-0,366	-0,332	0,390	0,075	6,7
Shopping CA	308,43	1389,72	-0,592	-0,763	0,923	0,996	-39,6
Shopping CNA	56,82	60,27	-0,580	-0,690	0,963	0,984	-14,3
Education CA	14,69	1132,31	-0,359	-0,314	0,427	0,483	-11,2
Education CNA	47,75	115,75	-0,743	-0,707	0,978	0,335	68,2
Other CA	1893,85	2182,60	-0,424	-0,439	0,818	0,984	-42,5
Other CNA	209,70	189,33	-0,430	-0,438	0,832	0,972	-40,6

Table D.6: α, β parameters and statistics for mode PT in Workday model O

Purpose	α_{A1}	α_{A2}	β_{A1}	β_{A2}	Cor A1	Cor A2	Diff RMSE (%)
Work CA	1,00	1,00	-0,001	-0,014	0,691	0,680	1,1
Work CNA	1,00	1,00	-0,041	-0,123	0,326	0,423	-8,4
Business CA	1,00	1,00	-0,219	-0,173	0,906	0,841	28,3
Business CNA	1,00	1,00	-0,167	-0,117	0,708	0,686	8,5
Education CA	1,00	1,00	-0,306	-0,314	0,091	0,503	12,0
Education CNA	1,00	1,00	-0,306	-0,355	0,017	0,013	1,7
Shopping CA	1,00	1,00	-0,204	0,000	0,538	0,342	24,9
Shopping CNA	1,00	1,00	-0,267	-0,234	0,707	0,733	-2,4
Other CA	1,00	1,00	-0,143	-0,143	0,973	0,968	4,5
Other CNA	1,00	1,00	-0,161	-0,168	0,877	0,874	-0,4

Table D.7: α, β parameters and statistics for mode Bicycle in Workday model O

Purpose	α_{A1}	α_{A2}	β_{A1}	β_{A2}	Cor A1	Cor A2	Diff RMSE (%)
Work CA	1795,95	1585,21	-0,282	-0,308	0,982	0,928	33,9
Work CNA	372,42	76,83	-0,294	-0,344	0,969	0,980	-5,1
Business CA	16,82	68,17	-0,326	-0,391	0,994	0,988	27,7
Business CNA	90,11	374,02	-0,378	-0,438	0,999	0,997	9,6
Shopping CA	125,46	635,77	-0,614	-0,922	1,000	0,999	65,8
Shopping CNA	64,81	94,00	-0,654	-0,937	0,999	0,999	1,2
Education CA	7,72	1102,26	-0,341	-0,377	0,971	0,995	-27,6
Education CNA	116,54	1573,01	-0,554	-0,772	0,999	0,979	76,4
Other CA	827,30	1581,87	-0,437	-0,612	0,999	0,998	32,8
Other CNA	237,74	352,42	-0,440	-0,592	0,997	0,999	1,2

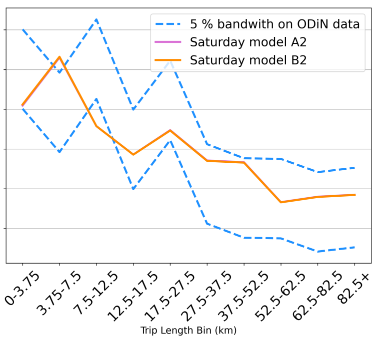

Figure D.1: TLD of purpose Work and mode Car for Saturday model

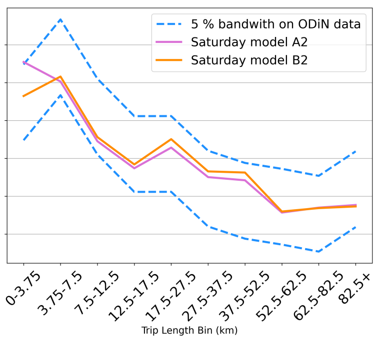

Figure D.2: TLD of purpose Socrec and mode Car for Saturday model

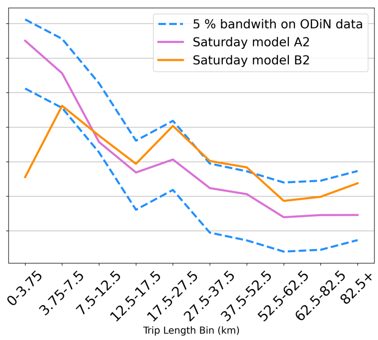

Figure D.3: TLD of purpose Sport and mode Car for Saturday model

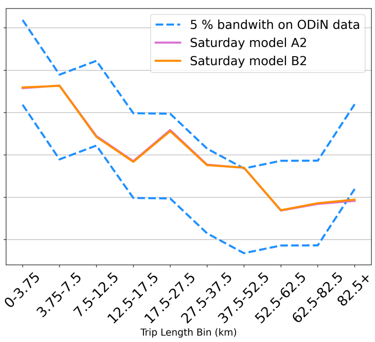

Figure D.4: TLD of purpose Visits and mode Car for Saturday model

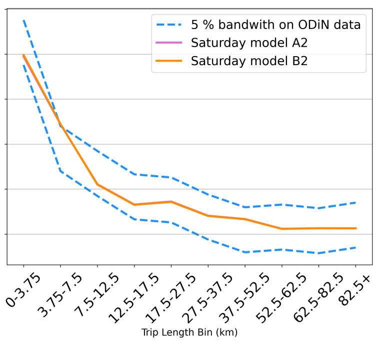

Figure D.5: TLD of purpose Drop off/pick up and mode Car for Saturday model

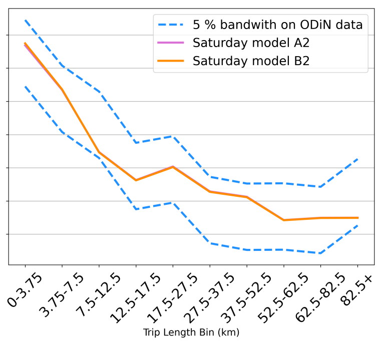

Figure D.6: TLD of purpose Other and mode Car for Saturday model

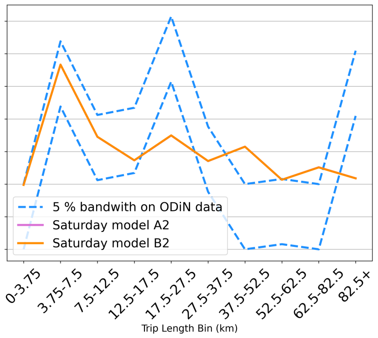

Figure D.7: TLD of purpose Work and mode PT for Saturday model

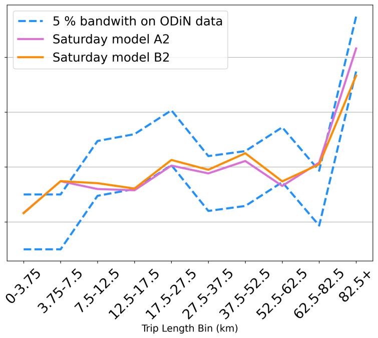

Figure D.8: TLD of purpose Socrec and mode PT for Saturday model

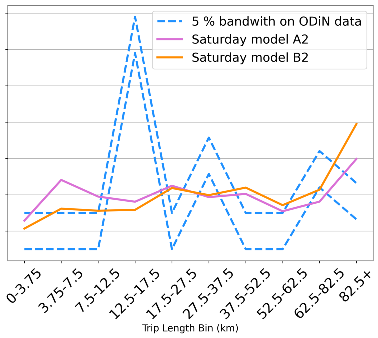

Figure D.9: TLD of purpose Sport and mode PT for Saturday model

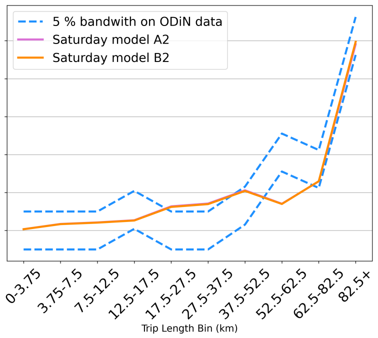

Figure D.10: TLD of purpose Visits and mode PT for Saturday model

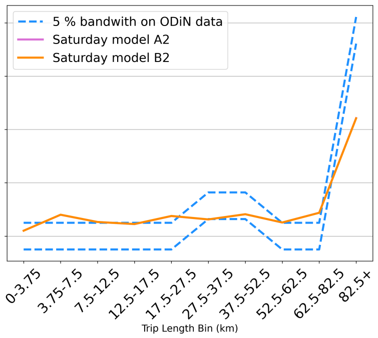

Figure D.11: TLD of purpose Drop off/ pick up and mode PT for Saturday model

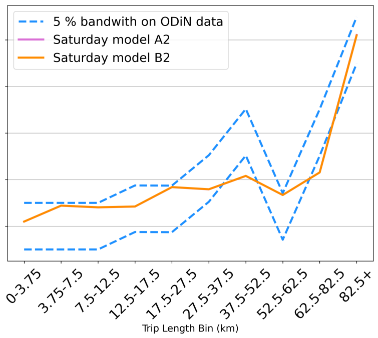

Figure D.12: TLD of purpose Visits and mode PT for Saturday model

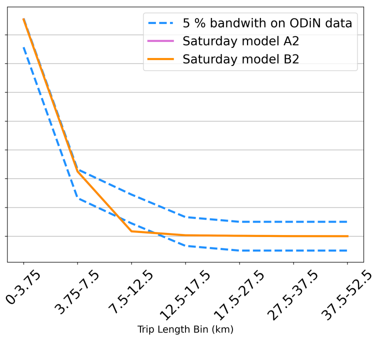

Figure D.13: TLD of purpose Work and mode Bicycle for Saturday model

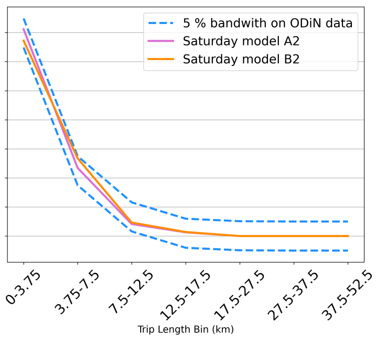

Figure D.14: TLD of purpose Socrec and mode Bicycle for Saturday model

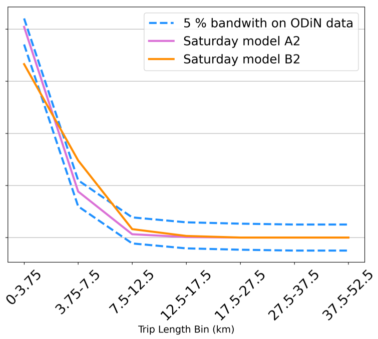

Figure D.15: TLD of purpose Sport and mode Bicycle for Saturday model

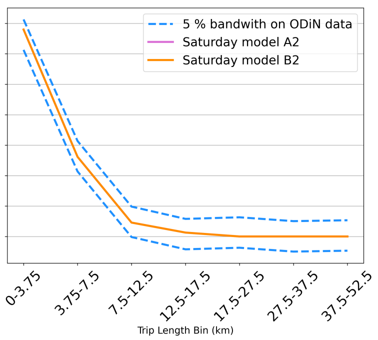

Figure D.16: TLD of purpose Visits and mode Bicycle for Saturday model

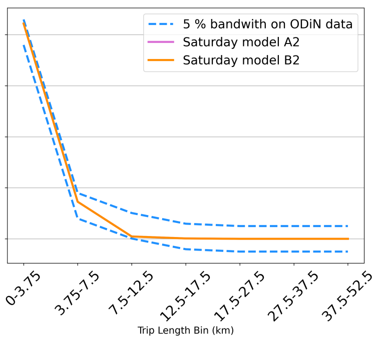

Figure D.17: TLD of purpose Drop off/pick up and mode Bicycle for Saturday model

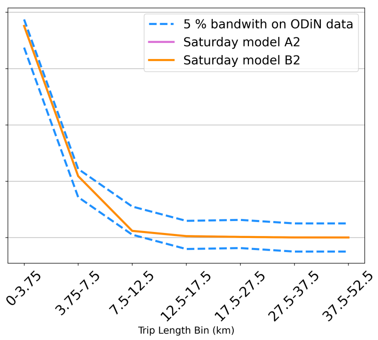

Figure D.18: TLD of purpose Other and mode Bicycle for Saturday model

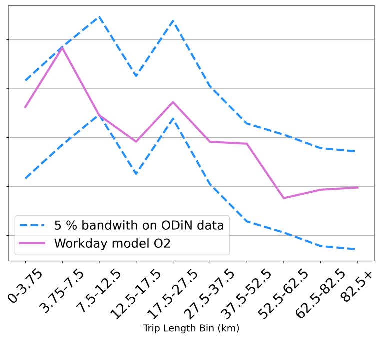

Figure D.19: TLD of purpose Work and mode Car for Workday model

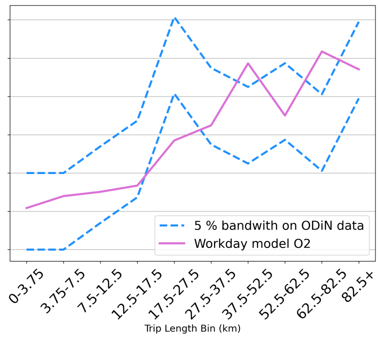

Figure D.20: TLD of purpose Work and mode PT for Workday model

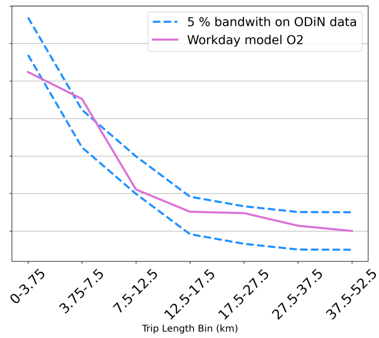

Figure D.21: TLD of purpose Work and mode Bicycle for Workday model

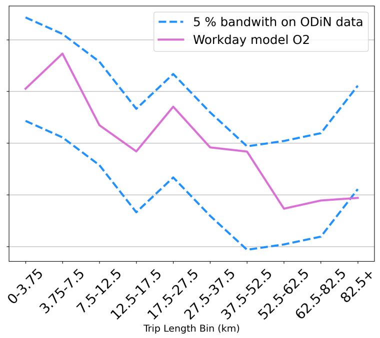

Figure D.22: TLD of purpose Business and mode Car for Workday model

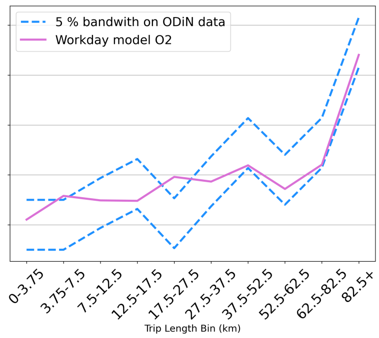

Figure D.23: TLD of purpose Business and mode PT for Workday model

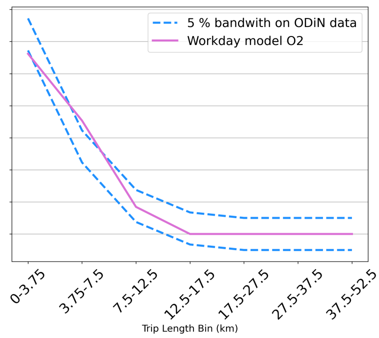

Figure D.24: TLD of purpose Business and mode Bicycle for Workday model

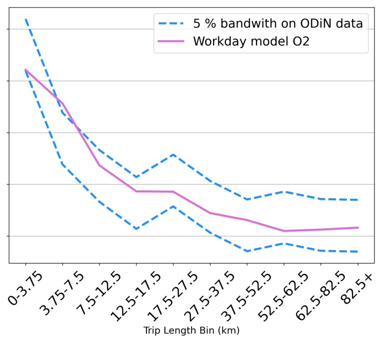

Figure D.25: TLD of purpose Educational and mode Car for Workday model

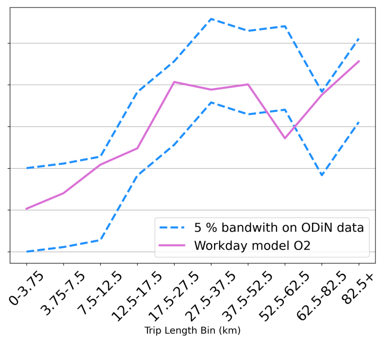

Figure D.26: TLD of purpose Educational and mode PT for Workday model

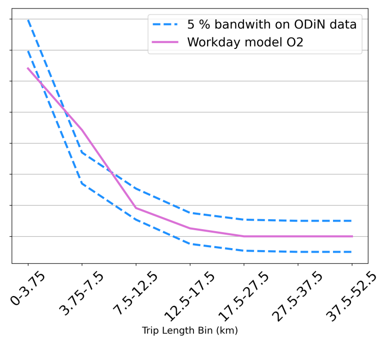

Figure D.27: TLD of purpose Educational and mode Bicycle for Workday model

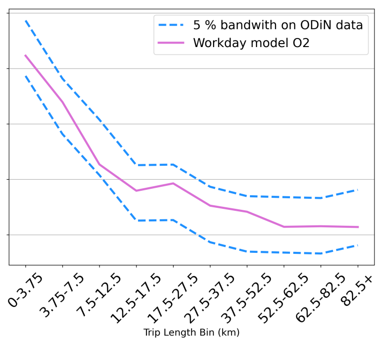

Figure D.28: TLD of purpose Other and mode Car for Workday model

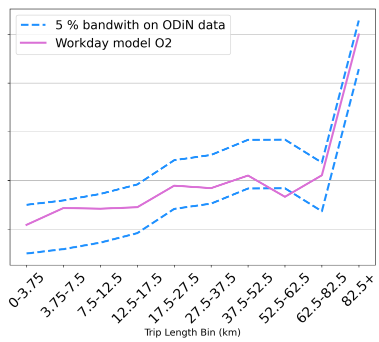

Figure D.29: TLD of purpose Other and mode PT for Workday model

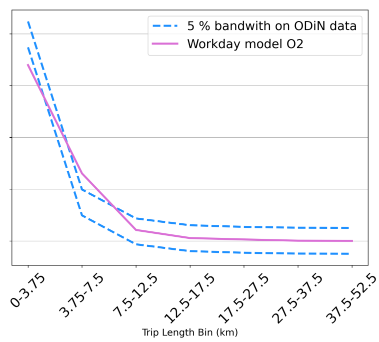

Figure D.30: TLD of purpose Other and mode Bicycle for Workday model

E

Appendix E: Additional tables for the travel demand analysis

Table E.1: Percentages of trip purpose distribution for trips arriving in Den Bosch for Saturday model versions and NVP

Purpose	Saturday model A2 (%)	Saturday model B2 (%)	NVP (%)
Work	14,1	12,2	15,8
Shopping	17,4	31,1	20,3
SocRec	11,1	11,4	19,1
Sport	9,0	5,3	6,0
Visits	18,1	14,1	26,3
Drop off/pick up	6,8	5,8	4,8
Other	23,5	20,2	7,7

Table E.2: Percentages of trip purpose distribution for trips arriving in Heusden for Saturday model versions and NVP

Purpose	Saturday model A2 (%)	Saturday model B2 (%)	NVP (%)
Work	7,1	8,5	13,7
Shopping	8,0	5,8	24,4
SocRec	13,7	15,2	14,2
Sport	12,0	1,8	8,1
Visits	22,7	25,0	29,0
Drop off/pick up	8,4	10,1	5,3
Other	28,1	33,7	5,4

Table E.3: Percentages of trip purpose distribution for trips arriving in Oss for Saturday model versions and NVP

Purpose	Saturday model A2 (%)	Saturday model B2 (%)	NVP (%)
Work	9,5	8,9	12,7
Shopping	7,8	19,1	24,0
SocRec	13,4	10,9	13,0
Sport	10,9	8,2	4,9
Visits	21,7	18,5	32,9
Drop off/pick up	8,4	7,9	6,5
Other	28,2	26,5	6,0

Table E.4: Percentages of trip purpose distribution for trips arriving in the city centre of Den Bosch for Saturday model versions and NVP

Purpose	Saturday model A2 (%)	Saturday model B2 (%)	NVP (%)
Work	13,79	5,21	3,20
Shopping	60,08	73,33	34,13
SocRec	3,98	11,95	32,08
Sport	4,73	3,10	0,25
Visits	6,13	2,14	21,98
Drop off/pick up	2,93	1,11	4,30
Other	8,37	3,16	4,07

Table E.5: Percentages of trip purpose distribution for trips arriving in the neighbourhood Schutskamp for Saturday model versions and NVP

Purpose	Saturday model A2 (%)	Saturday model B2 (%)	NVP (%)
Work	6,12	6,52	5,59
Shopping	44,00	51,53	31,00
SocRec	7,61	7,33	27,64
Sport	8,91	0,00	0,36
Visits	11,96	11,74	24,96
Drop off/pick up	5,55	5,94	5,18
Other	15,86	16,94	5,27

Table E.6: Percentages of trip purpose distribution for trips arriving in the area with department stores for Saturday model versions and NVP

Purpose	Saturday model A2 (%)	Saturday model B2 (%)	NVP (%)
Work	17,70	10,65	20,32
Shopping	81,87	88,95	73,69
SocRec	0,06	0,23	3,07
Sport	0,08	0,00	0,00
Visits	0,10	0,06	0,77
Drop off/pick up	0,05	0,03	0,00
Other	0,14	0,08	2,15