Causes and effects of suburban traffic dynamics
A case study in a municipality close to Munich

Sophia Cullen
Abstract

Causes and effects of suburban traffic dynamics

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The current transportation infrastructure in most cities and municipalities is not designed to cope with the continually increasing volume of traffic, especially during rush hours. Furthermore, in many cases, the increasing pressure has not yet been adequately compensated by sufficient expansion. The dynamic nature of this problem makes it very challenging to solve. Therefore, the purpose of this work is to investigate the causes and effects and their dynamics of the increasing strain on transportation infrastructure in suburban municipalities. This research is necessary in order to determine what needs to be changed to reduce traffic congestion effectively. Moreover, this study assesses the expectations of commuters regarding mobility. It is essential to take their opinions into account, as they are a significant cause of traffic congestion. Therefore, they need to accept any implemented solution in order to ensure a high adoption rate. In the process, the dynamics of the system and the opinions of commuters result in conceptual solutions aimed at improving the traffic situation in the long term.

The research involved conducting a single case study in a suburban municipality of the German city of Munich. In the course of this research, primary data was collected by means of a commuter survey and secondary data was also provided from an existing household survey. Moreover, empirical data was collected through a literature review as well as from numerous recognised online sources. The causes and effects of traffic dynamics were analysed by considering traffic as a system using Systems Thinking and System Dynamics methodology. The interrelated variables were visualised by creating a Causal Loop Diagram and drawing conclusions from it. In addition, conceptual solutions were developed by reviewing the works of previous researchers and taking into account the results from the System Dynamics analysis. The results of the commuter survey also played a crucial role in ascertaining the commuting habits and expectations of commuters regarding the transportation infrastructure.

The analysis of the Causal Loop Diagram revealed that in order to reduce traffic congestion, road expansion alone is not a viable solution due to rebound effects, which eventually result in increased car use and hence more traffic congestion. Therefore, in order to solve the problem in the long term, car use needs to be reduced to a significant degree. This can be achieved by implementing various solutions to nudge people towards using alternative modes of transport. Various pricing techniques such as free public transport are a possible method of approaching this topic. Furthermore, improving public transportation services and infrastructure using digitalisation and centralising various alternative modes of transport are among a number of appropriate ways of effectively reducing the traffic congestion problematic studied in this project. Hereby, the method of Change Management, usually used within organisations, can be applied to change the behaviour of society.
I would like to thank my supervisor Dr Martin Glas at IABG for your guidance throughout this research. No matter what support I needed, you gave me valuable advice and encouragement. Moreover, I would like to express my appreciation for my colleagues at IABG who offered their continuous advice. Firstly, thank you, Dr Elisa Canzani, for sharing your knowledge on Systems Thinking and System Dynamics and remaining patient with me throughout the process. Stephanie Öttl, I am very grateful for always being able to count on you when I felt stuck and needed some feedback. Oliver Bock and Sebastian Belkner, thank you for giving me the support I needed in Python and Latex. Without it, my plots and figures would not look half as professional. Thank you, Filiz Manyas, for helping me collect survey responses even when it rained and snowed. Your commitment was very encouraging. Finally, I would like to thank all remaining colleagues in the department IZ60. The pleasant work atmosphere has been incredibly motivating and precisely what I needed to complete my thesis.

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Finally, yet importantly, I would like to thank my family, classmates and friends for supporting me throughout my entire university life. I am fortunate to have you by my side.
Popular Science Summary

The current transportation infrastructure in most cities and municipalities is not designed to cope with the continually increasing volume of traffic, especially during rush hours. Furthermore, in many cases, the increasing pressure has not yet been adequately compensated by sufficient expansion. The dynamic nature of this problem makes it very challenging to solve. Therefore, the purpose of this work is to investigate the causes and effects and their dynamics of the increasing strain on transportation infrastructure in suburban municipalities. This research is necessary in order to determine what needs to be changed to reduce traffic congestion effectively. Moreover, this study assesses the expectations of commuters regarding mobility. It is essential to take their opinions into account, as they are a significant cause of traffic congestion. Therefore, they need to accept any implemented solution in order to ensure a high adoption rate. In the process, the dynamics of the system and the opinions of commuters result in conceptual solutions aimed at improving the traffic situation in the long term.

The research involved conducting a single case study in a suburban municipality of the German city of Munich. In the course of this research, primary data was collected by means of a commuter survey and secondary data was also provided from an existing household survey. Moreover, empirical data was collected through a literature review as well as from numerous recognised online sources. The causes and effects of traffic dynamics were analysed by considering traffic as a system using Systems Thinking and System Dynamics methodology. The interrelated variables were visualised by creating a Causal Loop Diagram and drawing conclusions from it. In addition, conceptual solutions were developed by reviewing the works of previous researchers and taking into account the results from the System Dynamics analysis. The results of the commuter survey also played a crucial role in ascertaining the commuting habits and expectations of commuters regarding the transportation infrastructure.

The analysis of the Causal Loop Diagram revealed that in order to reduce traffic congestion, road expansion alone is not a viable solution due to rebound effects, which eventually result in increased car use and hence more traffic congestion. Therefore, in order to solve the problem in the long term, car use needs to be reduced to a significant degree. This can be achieved by implementing various solutions to nudge people towards using alternative modes of transport. Various pricing techniques such as free public transport are a possible method of approaching this topic. Furthermore, improving public transportation services and infrastructure using digitalisation and centralising various alternative modes of transport are among a number of appropriate ways of effectively reducing the traffic congestion problematic studied in this project. Hereby, the method of Change Management, usually used within organisations, can be applied to change the behaviour of society.

Conclusions drawn from this degree project can guide counsels towards investing into adequate solutions that reduce traffic congestion in the long run. For example a higher priority on expanding the public transportation infrastructure and service should be set instead of ex-
panding road capacity. Furthermore, it can guide companies towards developing innovative products that satisfy the customers’ needs of a flexible, fast and hassle-free commute.
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</tr>
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<td></td>
</tr>
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<td>IABG</td>
<td>Industrieanlagen-Betriebsgesellschaft</td>
<td></td>
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<td>IHK</td>
<td>Industrie- und Handelskammer</td>
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</tr>
<tr>
<td>Kirchheim</td>
<td>Kirchheim bei München</td>
<td></td>
</tr>
<tr>
<td>MMR</td>
<td>Munich Metropolitan Region</td>
<td></td>
</tr>
<tr>
<td>MoT</td>
<td>Mode of transportation</td>
<td></td>
</tr>
<tr>
<td>PM</td>
<td>Particulate matter</td>
<td></td>
</tr>
<tr>
<td>PSS</td>
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<td>PT</td>
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<td>WP</td>
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Chapter 1

Introduction

This chapter firstly introduces the reader to the topic by giving some background information. Secondly, the problem is described in detail, which leads to the purpose of the thesis. Moreover, the research questions (RQs) that guide throughout the whole project are stated. Moreover, the scope of this project is stated. The chapter then ends by outlining the entire thesis.

1.1 Background

Traffic congestion is an emerging issue that many cities and municipalities face and is caused by a number of factors described in this thesis. The main factor that is described is urban sprawl and the effects that come with it. Moreover, the increase in car use during the past years that is partly due to urban sprawl but also changes in preferences are a cause of increasing traffic congestion.

Even though several solutions have been implemented in some cities and countries, no long-term solution has been found that avoids traffic congestion to increase again after some time has passed and can be applied universally in suburban municipalities. The strain on transportation infrastructure in municipalities around cities has increased significantly during the past years. Moreover, the transportation infrastructure is not designed to cope with the increasing pressure, especially during rush hours. This might affect factors such as the parking situation, traffic conditions, noise pollution and air quality. Furthermore, the increasing strain is not always met by adequate expansions, such as improvements in public transportation (PT) and road infrastructure.

Previously, some cities and countries have taken measures to reduce the pressure on transportation infrastructure. Among them are a variety of pricing techniques such as in Tallinn (Estonia) (Cats et al.; 2017), Brussels (Belgium) (de Witte et al.; 2006) and Hasselt (Belgium) (van Goeverden et al.; 2006), where free PT was implemented. Other cities have introduced the method of tolls, like in Stockholm (Eliasson et al.; 2009) and Singapore (Goh; 2002), where a fee needs to be paid to enter certain roads.

Many more solutions of other researchers to solve traffic congestion are also discussed in this project. However, further research needs to be done to ascertain which solutions solve traffic congestion in the long run and can be implemented for suburban municipalities universally. Since traffic congestion and related problems are expected to continue growing in the future, it is essential to tackle this issue as soon as possible. Moreover, the nature of this problem is complex and dynamic, which is a reason why current solutions are not yet sufficient to solve traffic congestion.
1.2 Problem statement

As already described, the problem of increasing traffic congestion is of a very dynamic nature because many factors influence people’s travel behaviours and also affect many other variables in the traffic system. The current transportation infrastructure in most cities and municipalities was built to cope with the traffic volume of the time of its construction. Back then, travel behaviours were different and shorter commuting distances (Kinigadner et al.; 2016) and different free-time activities were the norm. Therefore, the current infrastructure is not designed to cope with the continually increasing strain of modern times, especially during rush hours. Furthermore, the increasing pressure on the infrastructure has not yet been met by adequate expansion because the transportation system is affected by a large number of dynamically interrelated variables. The situation makes it very challenging to identify the exact causes and what effects they have. Changing one variable in the system does not necessarily solve the traffic congestion problematic, as congestion increases again in the long run, which is called reinforcing feedback. Therefore, it is necessary to look at the system as a whole and analyse the dynamics within it. This approach is especially crucial because traffic congestion is likely to increase in the future if the situation is not improved.

For instance, a forecast by the planning department of the city of Munich stated that the rush hour will persist throughout the whole day by 2030 (Hutter; 2018). This is due to a prospering economy and the high population growth (by approximately 180,000 people in the last ten years) that has come with it (Möbert; 2019). Not enough expansion has been put in place to accommodate this, such as the rail network which has not been adequately expanded.

An investigation on the dynamics of the causes and effects of traffic congestion is necessary in order to find out which components within the system need to be changed so that traffic congestion can be reduced without it leading to a reinforcing feedback. Moreover, the expectations of commuters regarding mobility are to be assessed. It is essential to take their opinions into account because commuters cause traffic congestion to a high degree. Therefore, any implemented solution needs to be accepted by them in order to ensure a high adoption rate. This leads to the purpose of this project.

1.3 Purpose

The purpose is to investigate the dynamics of the causes and effects of the increasing strain on transportation infrastructure of suburban municipalities. In the process, the dynamics of the system and the opinions of commuters will result in conceptual solutions aimed at improving the traffic situation in the long run.

1.4 Research questions

In order to fulfil the purpose of the degree project, the following RQs are answered. Since the degree project focuses solely on suburban municipalities, this fact is not explicitly pointed out in each RQ.

1. What are the causes and effects of the increasing strain on the transportation system with their dynamics?

2. Which solutions are feasible in order to accommodate the increasing strain on transportation infrastructure during peak hours?
1.5 Delimitations

For RQ 1, the SD methodology is used and therefore a qualitative CLD is created to assess the interrelatedness of the variables within the traffic system in Kirchheim. The next step would be to convert the CLD to a quantitative stock-and-flow diagram in order to simulate the patterns of behaviour and to assess what conceptual solutions to improve the traffic situation are feasible. Nevertheless, this exceeds the scope of this thesis and is to be conducted in future research.

The conceptual solutions developed in RQ 2 are only a small number of solutions feasible to reduce traffic congestion. There are mainly two groups of solutions, the ones that draw people towards using car alternatives with hard measures such as an increase in pricing or giving restrictions on car use. The other type is soft measures that incentivise the use of car alternatives by making them more attractive, for example, cheaper or more comfortable. This thesis does not include all possible solutions, but the central message of how to influence society with Change Management is communicated.

1.6 Outline

The following chapters aim to guide the reader towards fulfilling the purpose of investigating suburban traffic dynamics and finding long-term conceptual solutions. Chapter 2 explains the literature related to the research topic. It explains the causes and effects of traffic congestion that previous research has identified and names a number of solutions that other cities and countries have implemented. The theoretical framework is explained in chapter 3, where the theories and methods used for the analysis are stated. The focus hereby is on Systems Thinking, System Dynamics and Change Management. In chapter 4, the method is described by explaining the research design, data collection and analysis. It also includes information on the validity of the research, possible variability and ethics. The empiric findings chapter (chapter 5) outlines the case study conducted in Kirchheim and the dynamics of the causes and effects of traffic congestion in the municipality. Furthermore, it summarises some complaints the stakeholders have and their suggestions on how to improve the situation. Moreover, in this chapter, the results of a commuter survey conducted for this thesis are stated. The analysis chapter (chapter 6) uses insights from the literature review and empiric data to answer the two RQs. First of all, a CLD is presented to illustrate the traffic dynamics in suburban municipalities and Kirchheim in general. Additionally, various conceptual solutions are analysed regarding their feasibility. Chapter 7 discusses the results, where the main focus is on examining whether the results from the analysis can be applied to other suburban municipalities with similar characteristics. Moreover, the analysis is viewed critically to see whether it could have been done differently. A Change Management model is applied in order to find out whether nudging people towards a habitual change can be achieved. Lastly, the conclusions and further research chapter (chapter 8) summarises the research work and provides an outlook for future work.
Chapter 2

Literature review

The literature review provides an overview of the causes of traffic congestion as identified by researchers. Moreover, the different effects of congestion on the economy and also the physical and psychological health of individuals are discussed. The Literature Review concludes with solutions that researchers have come up with or that cities and countries have implemented.

2.1 Causes of traffic congestion

To begin with, the main aspects that cause traffic congestion in the suburban area are the increase in car use, urban sprawl and fixed work hours. Consequently, the next sections deal with these causes in greater detail.

2.1.1 Car usage development

According to Proff and Fojcik (2018), on average, every car is occupied by 1.4 passengers and needs, at a speed of 30 km/hour in inner cities, 65 m² of space per person, including the car’s size and braking distance. Compared to private vehicles, a bus with 20% occupancy needs 8 m² and a train with the same occupancy 5 m² per passenger (Randelhoff; 2015). The land use per passenger per vehicle tells us that the higher the car usage, the greater traffic congestion. Hereby, figure 2.1 illustrates the space each passenger needs, depending on the type of vehicle.

![Figure 2.1: Land use per person and vehicle (own representation based on Randelhoff (2015))](image)

Thomson and Bull (2002) look at the increase in car usage over time in Latin America. Due to an improved economy and higher incomes, cars have become more affordable and also more accessible. Furthermore, they mention that since cities are growing, the use of cars is increasing as well. In Europe, too, car use has increased significantly over time. In the European Union (EU), the number of cars in use grew by 5.6% from 243.3 million to 257.1 million between 2012 and 2016. To be more specific, in Germany, the number of cars in use rose by 5.5% from 43.4 million to 45.8 million during the same time (ACEA; 2019).

For comparison, during the same time frame, the population in the EU increased by 1.2% from 504 million to 510.2 million and in Germany by 2.3% from 80.3 million to 82.2 million.
2.1. CAUSES OF TRAFFIC CONGESTION

(Eurostat Statistics Explained; 2019). These figures show that the increase in car use is not proportional to the growth in population.

The table below (2.1) gives an overview of population and car increase between 2012 and 2016.

**Table 2.1:** Development of population and number of cars between 2012 and 2016 in the EU and Germany (ACEA; 2019; Eurostat Statistics Explained; 2019)

<table>
<thead>
<tr>
<th>Place</th>
<th>Year</th>
<th>Population</th>
<th>Increase</th>
<th>Cars in use</th>
<th>Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>EU</td>
<td>2012</td>
<td>504 m</td>
<td></td>
<td>243.3 m</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2013</td>
<td>505.2 m</td>
<td>0.2%</td>
<td>245.2 m</td>
<td>0.8%</td>
</tr>
<tr>
<td></td>
<td>2014</td>
<td>507.2 m</td>
<td>0.4%</td>
<td>247.6 m</td>
<td>1.0%</td>
</tr>
<tr>
<td></td>
<td>2015</td>
<td>508.5 m</td>
<td>0.3%</td>
<td>251.9 m</td>
<td>1.7%</td>
</tr>
<tr>
<td></td>
<td>2016</td>
<td>510.2 m</td>
<td>0.3%</td>
<td>257.1 m</td>
<td>2.1%</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>1.2%</td>
<td>5.6%</td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td>2012</td>
<td>80.3 m</td>
<td></td>
<td>43.4 m</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2013</td>
<td>80.5 m</td>
<td>0.2%</td>
<td>43.9 m</td>
<td>1.2%</td>
</tr>
<tr>
<td></td>
<td>2014</td>
<td>80.8 m</td>
<td>0.4%</td>
<td>44.4 m</td>
<td>1.1%</td>
</tr>
<tr>
<td></td>
<td>2015</td>
<td>81.2 m</td>
<td>0.5%</td>
<td>45.1 m</td>
<td>1.6%</td>
</tr>
<tr>
<td></td>
<td>2016</td>
<td>82.2 m</td>
<td>1.2%</td>
<td>45.8 m</td>
<td>1.6%</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>2.3%</td>
<td>5.5%</td>
<td></td>
</tr>
</tbody>
</table>

2.1.2 Urban sprawl

Another aspect that affects traffic congestion in suburban municipalities is urban sprawl. An increasing number of people move away from cities due to several reasons. Therefore, Oueslati et al. (2015) discuss the factors contributing to urban sprawl in European cities. They found out that it is happening due to a growing spatial scale. It means that cities tend to grow due to fragmentation. Cities have become less mono-centric and instead, more poly-centric. Moreover, urban sprawl also occurs due to an increased acceptance of longer commute distances (Guth et al.; 2010). According to Pfaff (2014), the commuting distance in Germany has increased significantly in recent years. This increase is due to various reasons. Firstly, nowadays it is more common for both spouses to have a job. Therefore, it can be challenging to find a place of residence that is near to both spouses’ workplaces. Moreover, housing preferences, such as owning a house with a garden, are more affordable in suburban areas compared to the urban space, whereas most businesses are located in cities. On the one hand, people want to fulfil their need for attractive housing and, at the same time, be satisfied with their job. It might not be possible to meet these two needs close to each other, which leads to longer commuting distances. Furthermore, temporary jobs are more common these days, which results in a greater mobility requirement. Many people think they can compensate for the longer commute with higher salaries. However, they underrate the real cost of commuting when committing to jobs. These commuting costs are not only financial ones but also the psychological costs, such as stress and time. The effects of these will be explained later in chapter 2.2.2. As stated by Hennig et al. (2015), high sprawl values are particularly found in western Europe, including western Germany.
2.1.3 Peak hours

Not only the urban sprawl and car use development have contributed to traffic congestion. It is also caused by peak hour traffic due to fixed work hours. In most companies in Munich, working hours vary starting between 7 a.m. and 9 a.m. and finishing between 4 p.m. and 6 p.m. Therefore, traffic peak hours usually occur during this time frame (Altmann; 2019). It can therefore be assumed that roads are under occupied outside and over occupied within these hours, which leads to traffic congestion during peak hours. Additionally, road works on the motorways to and from Munich reduce road capacity, which increases congestion during peak hours even more (ibid.).

2.2 Effects of traffic congestion

Traffic congestion leads to diminished accessibility of cars at various places. It takes longer to arrive at destinations and sometimes it is even impossible during rush hours. It is noticeable that the larger the cities are, the higher the congestion usually is (Moya-Gómez and García-Palomares; 2017).

Whereas this direct effect of congestion seems very obvious, other fundamental effects tend to be forgotten. These can be effects on the economy and on the psychological and physical health of individuals. Therefore, these factors are explained in the subsequent three subheadings.

2.2.1 Economic effects

Hymel (2009) explains that there is a strong link between traffic congestion and a decrease in employment growth. He (ibid.) also notices that the decrease in employment growth is higher the more congested the area is. Another research done by Jin and Rafferty (2017) in metropolitan regions in the United States describes the exact same effects. This article also discusses the negative consequence on income growth. In order to solve this issue, they mention that new road infrastructure can positively affect the level of employment in that area and increase the salaries of employees (ibid.). It furthermore improves the output of employees, which is an indication that it improves the motivation and hence, the efficiency of the individuals (ibid.).

2.2.2 Psychological and physical health effects

The first thought that might come to one’s mind is that an increase in commuting distance has a negative impact on the overall life satisfaction of the commuter. Stutzer and Frey (2008) came to the conclusion that people who commute have a lower life satisfaction. This is, to a high degree, due to the stress people experience (ibid.).

A literature review conducted by Pfaff (2014) discusses that commuters complain about the lack of free time stolen by the time they spend on the roads and exhaustion. The time pressure can have negative effects on health, such as the quality of sleep and life happiness. Moreover, the reduced amount of free time caused by the increased travel time gives individuals less opportunity to recover from work and leads to higher stress levels (ibid.). Psychosomatic issues are often the consequence and, due to time constraints, only the symptoms instead of the causes are treated. Furthermore, they point out that this effect is not worsened drastically when the commuting distance increases. This slight increase in burden is small compared to the burden of moving (ibid.). Another result is that an economic decrease in the place of residence significantly lowers the overall life satisfaction of employees (ibid.).
Nevertheless, Fichter (2015) argues that commuting itself does not make people unhappy. Many factors play a role in happiness – health, a harmonious and intact family, a functioning social life, a good relationship and a balanced and meaningful workplace. The factors making commuting a negative experience are delays, crowds, jams and having to travel too long distances (ibid.). However, some factors can contribute to a more enjoyable commute, for instance, entertainment, being able to work, relaxation and cognitive restructuring. It works as a coping strategy to make a hectic commute tolerable, such as reinforcing in one’s mind the reason why one takes a commute upon oneself. He points out that luxury plays a role when choosing a mode of transportation (MoT). A first class train ticket or a more comfortable car can make a big difference in terms of travel perception. Cyclists are said to be the happiest commuters. This is due to physical activity, being outdoors and a slower lifestyle (ibid.).

Lorenz (2018) talks about subjective well-being and the factors influencing it when commuting. She says that commuting does not affect overall life satisfaction, but rather affects the subjective well-being of particular life areas. According to her, it is possible to compensate for the struggles of commuting through higher salaries or housing compensations.

Higgins et al. (2018) state that the happiness of the commute is dependent on how the time is spent. Moreover, the satisfaction and tolerance for the travel time are drastically lowered the more congestion occurs. However, they have found out that satisfaction with one’s commute cannot be generalised to one’s overall life satisfaction (ibid.). They concluded that firstly, the travel time needs to be shortened and secondly, congestion needs to be reduced (ibid.). This can be achieved by spreading the time that individuals commute more broadly and hence, spread the number of commuters over a larger time frame (ibid.).

Air pollution
More traffic congestion leads to higher levels of air pollution. Thus, the effect of it is discussed in this section. Different sources discuss what effects an increase in pollutants has on the health of individuals.
A study conducted in the city of Munich with a group of children living in different environments showed the impact of the exposure to urban traffic pollutants (Nicolai et al.; 2003). Children living close to roads with high traffic density complained about respiratory troubles such as asthma, cough and wheeze (ibid.).

Furthermore, according to research by van Vliet et al. (1997), children living close to busy roads are more likely to have respiratory issues compared to those living in calmer neighbourhoods. They also came to the conclusion that girls are more highly affected than boys. Moreover, Dockery et al. (1993) found out that there is an increased association between fine particulate air pollution and higher death rates in cities in the United States. Beyond that, Pope et al. (1995) state that fine particulate air pollution and sulphate at levels observed in U.S. cities are associated with increased death rates.

Noise pollution
Traffic congestion does not only lead to higher levels of air pollution, but also to higher noise pollution, which can have radical psychological and physical effects. A study conducted by Recio et al. (2016) found out that excessive and ongoing traffic noise pollution can lead to stress. A phenomenon called emotional flight can occur, which is a way of isolating the annoyance from consciousness. This is a way of lowering the emotional strain on the individual.
However, further ongoing noise can lead to an allostatic overload, which can then cause a mental breakdown (ibid.).

Furthermore, the effects described previously can also lead to physical effects (Recio et al.; 2016). A mental breakdown, caused by an allostatic overload, can lead to "respiratory infections, increased oxidative stress, accentuated endothelial dysfunction, and aggravation of atherosclerosis". Moreover, it "exhibits lymphocyte adhesion and fosters blood clotting". Last but not least, it can support an "insulin resistance in the long run, contributing to the development of type 2 diabetes" (ibid.).

2.3 Solutions

This section presents several solutions that have been implemented in other cities or countries or that researchers have identified.

2.3.1 Telecommuting

One way of reducing commuter traffic is by giving employees fewer incentives to travel to work. This can be done by allowing them to work from home. Moeckel (2017) claims that if employees spend part of their working time at home, the trips taken to get to work will be reduced. However, he notes that this option gives people an incentive to live further away from their workplace, which can increase urban sprawl. As mentioned previously, urban sprawl has both positive and negative sides to it (ibid.).

2.3.2 Pricing techniques

Two ways of making use of pricing techniques are explained below. These can be leveraged by either raising the cost of certain MoTs to reduce their use or by cutting costs on certain MoTs to additionally incentivise their use.

Road pricing

To give commuters an incentive to use more PT, Singapore introduced Electronic Road Pricing (ERP) in a restricted zone in 1998, as explained by Goh (2002). This strategy was implemented by introducing differentiated pricing. More utilised roads are charged higher, and less used roads are charged lower. This is done in order to encourage people to switch to either the less utilised roads or PT (ibid.). Moreover, prices during peak hours are higher than during off-peak hours. Hence, the traffic is spread out throughout the city and also across the day. However, ERP by itself cannot tackle traffic congestion and access to the restricted locations needs to be improved by expanding PT infrastructure. Besides, society must be educated to make them understand that their travelling habits need to be adjusted (ibid.).

Some downsides of ERP are stated by Goh (2002). Firstly, sometimes the rates encourage so many people to switch to less utilised roads that the previously more congested become underutilised. Besides, since car movements are tracked by the ERP and saved on a central computer, this could lead to data protection and privacy issues (ibid.).

As stated by Eliasson et al. (2009), in 2006, a trial was conducted in Stockholm to test whether congestion charging would reduce traffic congestion and improve the efficiency of the traffic system. It was designed to charge a toll for vehicles entering the inner city of Stockholm. The charges varied for different times of the day and no fees were charged on weekends, public holidays and evenings. Furthermore, PT services were extended. The ef-
fect on the traffic was a 22% reduction of vehicles entering the zone during the charging times. Apart from that, vehicle travel time fell by one third during the morning rush hour and halved in the afternoon rush hour. Travel patterns also changed, which led to a 6% increase in PT trips and no increase in carpooling or telecommuting. The environmental effects should also be taken into account. The CO\textsubscript{2} emissions from traffic have decreased by 14%. 25 to 30 fewer premature deaths are expected yearly in Stockholm because of better air quality. Moreover, the perceived environment also improved according to Stockholm’s citizens. Because the trial period was successful, after a referendum the government decided to retain the road pricing system permanently (ibid.).

Both authors point out that improving PT infrastructure alone is not a solution to reducing congestion, but merely an appropriate measure to complement other strategies such as road pricing (Goh; 2002) Eliasson 2009.

Free public transportation

Several researchers have covered the approach of decreasing private vehicle use by introducing free PT. A case study undertaken in Brussels by Macharis et al. (2006) shows that the adoption rate of fare-free PT is higher among price-sensitive groups such as students, compared to the average user. Furthermore, they found out that free PT does not always increase the number of users of PT because other qualitative factors also need to be considered. For example, drivers of business cars are less likely to be persuaded to choose PT. As mentioned by de Witte et al. (2008), free PT alone will not persuade users to switch. The quality of the PT system also needs to be improved.

The city of Tallinn introduced fare-free PT for all of the city’s citizens. The goal was to achieve a modal shift from using cars to PT. This goal was partly achieved, and many car drivers switched from using the car to PT. However, the change also caused many people who usually would have walked to change to using buses for the journey. Moreover, the overall perception of PT in Tallinn improved. (Cats et al.; 2017)

An approach by which a bus route in Leiden in the Netherlands made PT free of charge for a limited time was discussed by van Goeverden et al. (2006). During this time, usage increased from 1,000 to 3,000 passengers per day. Of these new passengers, 55% used to commute using private vehicles. Even though a high PT adoption rate was achieved, the congestion on the motorways in this area only reduced slightly. Another approach conducted in Hasselt in the Netherlands caused the number of PT passengers to increase by tenfold (ibid.).

An experiment was conducted in Kyoto in Japan, in which a one-month free bus pass was handed out to 23 car drivers (Fuji and Kitamura; 2003). Their car driving and bus usage habits were measured before, immediately after and one month after the study. The study showed that their bus usage increased significantly and their car usage decreased, even after the free one-month bus ticket had expired (ibid.).

Moreover, Thøgersen (2009) discusses a free one-month travel ticket for PT that was implemented in Copenhagen. PT usage increased significantly during this time and dropped slightly after the one-month trial. However, it remained higher than before the trial was carried out.
The trial of introducing free PT for a limited amount of time that resulted in higher PT usage even after the trial had ended led to the conclusion that a short-term change can achieve a long-term habitual change.

2.3.3 De-sprawling techniques

As mentioned previously, one cause of traffic congestion is urban sprawl. Hennig et al. (2015) identified various techniques to implement a de-sprawling strategy. To begin with, urban sprawl should be observed and documented so that sprawl hotspots can be identified by counting traffic. Next, anti-sprawl policies should be put in place that set limits, targets and benchmarks regarding where people are allowed to settle down. Additionally, sensitive areas, for instance, forests, should be protected from sprawl. Furthermore, long-term settlement planning should be established in cooperation with other municipalities. Lastly, different economic instruments are to be used, such as higher property taxes in high-sprawl areas (ibid.).

2.3.4 Ride sharing

According to Proff and Fojcik (2018, p. 71-72), in order to reduce traffic congestion, they suggest using space more efficiently. On average, every car is occupied by 1.4 passengers and needs, at a speed of 30 km/hour in inner cities, 65 m$^2$ of space per person including the car’s size and braking distance. They mention that one would think bicycles are a space-saving alternative compared to other modes of transport. However, a cyclist needs 41 m$^2$ of space at 30 km/hour. Compared to private vehicles, a bus with 20% occupancy needs 8 m$^2$ and a train with 20% occupancy 5 m$^2$ per passenger at the same speed (Randelhoff; 2015).

When vehicles are not used, they stand around and take up space. Therefore, they suggest reducing the amount of space wasted by ensuring that vehicles are always on the move and by sharing vehicles (Proff and Fojcik; 2018, p. 71-72).

Li et al. (2016) analysed whether ride sharing, as practised by Uber, reduces traffic congestion. Ride sharing increases vehicle occupancy and reduces car ownership. Moreover, peak hour traffic prices give the people that do not necessarily have to travel at certain times an incentive to choose a time outside of the peak hour time frame.

A ride sharing service in China known as Didi Chuxing was observed by Yu et al. (2017). The researchers found out that vehicle sharing has a positive influence on the environment because it reduces pressure on the transportation infrastructure. Firstly, it reduces emissions such as fine particulate pollution in the form of SO$_2$ and NO$_x$. Moreover, when customers request a ride online, it also gives the ride sharing provider feedback on where and when the demand for ride sharing is the highest. This information can provide insights into where the hotspots are and where the PT infrastructure needs to be improved. They also point out that ride sharing reduces the willingness to buy a car and induces a modal shift from using a private vehicle or a taxi.

Even though the sharing economy seems like an advisable method to reduce traffic, rebound effects should not be ignored. Proff and Fojcik (2017) point out that by having easier access to products, the demand for them increases. This could also be the case with ride sharing. Some people could potentially switch from PT to using cars, which could then in turn increase congestion.
2.3. SOLUTIONS

Shared autonomous vehicles  A report by Kloth (2015) on a study conducted in Lisbon assessed whether autonomous vehicles are capable of solving the problem of congestion. They distinguished between two types of autonomous vehicles – cars that can be shared simultaneously by passenger groups (“TaxiBots”) and cars that give lifts to single passengers (“AutoVots”). They assessed two scenarios – TaxiBots in combination with high-capacity PT (scenario 1) and AutoVots without the combination of high-capacity PT (scenario 2). Firstly, the results of scenario 1 are discussed. It is capable of removing 90% of cars in a European city the size of Lisbon. Nevertheless, the researchers mention that the overall kilometres travelled by car would increase by 6%, but that peak-hour traffic would reduce by 65%. In scenario 2, 80% of cars could be removed from the roads. However, the kilometres travelled by car would increase by 89%. During peak-hour traffic, the number of cars would be lowered by 23%. Overall, both scenarios would free up parking space that could be used for public areas. The study points out that high-capacity PT is critical when implementing shared self-driving vehicles.

Proff and Fojcik (2018, p. 73) point out that autonomous carsharing would enhance traffic safety since 90% of accidents are caused by human failure. Additionally, one shared car has the potential to replace six vehicles. Hence, the standing time per vehicle can be minimised, and land use is reduced.

2.3.5 Mobility hubs

The concept of mobility hubs was discussed by Proff and Fojcik (2018, p. 313-328). They act as logistical hubs where several mobility services are provided. Complementary services can be connected at this hub so that a multi-modal route can be created seamlessly. The mobility services available at the hub can be bike sharing, car sharing, long-distance bus services, taxis, PT, and so on. This collaborative business model should also be connected digitally. All timetables, ticketing, booking, intelligent routing and all other information can be provided on a central platform, which should be made accessible through smartphone applications and other services. As an outlook, the authors point out that the concept of mobility hubs needs to be in line with other technology trends such as electric mobility and autonomous driving. These trends affect location planning and the business model. Autonomous shuttle buses are a reasonable addition to mobility hubs.

2.3.6 Air mobility

A report by von Ammon (2018) explains that conquering the third dimension is a way of avoiding a traffic collapse. Companies such as Airbus have approached this topic by developing an electric vertical take-off and landing (eVTOL) aviation vehicle called CityAirbus. It is possible to transport up to four passengers, who can book a seat on-demand by using a smartphone application. However, to enable this radical innovation, the necessary infrastructure first needs to be in place, such as ports for boarding and alighting and parking spaces, which has not yet been implemented in most cities.
Chapter 3

Framework

To better understand the causes and effects of traffic congestion, Systems Thinking (ST) and System Dynamics (SD) are used. ST is an approach for studying the dynamic behaviours of a system as a whole rather than in isolation. SD is a method for understanding the changes and complexity of a dynamic system over time. The theories ST and SD are used for the analysis of RQ 1. Moreover, the method of Change Management is explained, which is exploited in the analysis of RQ 2.

3.1 Thinking in systems

Before going deeper into the theory, it is important to define what a system is. As stated by Meadows and Wright (2009, p. 2), "a system is a set of things [...] interconnected in such a way that they produce their own pattern of behavior over time". It is crucial to keep in mind that each component of a system is connected to another one, in order to understand real-world dynamics by thinking in systems.

3.1.1 Systems Thinking

ST is a holistic approach that looks at a system as a whole, in which all components are interrelated. The bigger picture of the system is considered, in which the different variables interact with one another and are interdependent, instead of observing isolated incidents. This approach makes it possible to detect different patterns of behaviour within systems. ST also makes it possible to identify successful long-term solutions to prolonged, chronic problems that have failed to be solved in the past but essentially need solutions (Kirkwood; 2013, p. 1-3).

To better understand the conceptual framework of ST, an example of a rainstorm is given. When dark clouds are visible in the sky, humans know that it will rain shortly after (Senge; 1990, p. 10). After some time, the water feeds into the groundwater, and the sky clears up. Even though the events do not take place immediately after one another, we still know that they are interrelated and part of the system of a rainstorm. It is only possible to understand the system by looking at the whole and not at the isolated events, such as rain or dark clouds (ibid.).

Another example is an experiment conducted in 1973 in the basement of a building at Stanford University, where college students took over the role of prisoners and guards in a fake prison (Senge; 1990, p. 34). At first, the mock prisoners showed little resistance and the mock guards mild assertiveness. However, after a few days had passed, the experiment got out of hand when the guards physically abused the prisoners. Finally, after six days, the trial was called off due to signs of depression and psychosomatic illnesses of participants.
This example illustrates how seemingly irrelevant behaviour can build up to create a much bigger problem (ibid.).

### 3.1.2 System Dynamics

Jay Forrester developed SD (Forrester; 1989) at the Massachusetts Institute of Technology in the 1950s and is a modelling approach that links qualitative and quantitative models in order to understand the dynamics of complex systems. SD aids in expanding the boundaries of our traditional thinking by using ST that helps us to capture the feedback structures of a system. An SD model can serve as support in decision-making, but it is not an appropriate tool for generating precise forecasts. When developing an SD model, first of all, a CLD is created to visualise the cause-and-effect loops qualitatively. From this diagram, hypotheses on system behaviour can be drawn. In a next step, a quantitative stock-and-flow model is created from the CLD. Since this thesis is a qualitative study, creating a stock-and-flow model exceeds its scope. Moreover, SD modelling is only used to structure and visualise the patterns of behaviour between the different variables. However, a simulation will be conducted in future research. Instead, the capabilities of a CLD are exploited, and the qualitative modelling presented in this work can provide a solid basis for future quantitative studies on traffic dynamics in suburban municipalities (Sterman; 2000). The basic concepts of SD are explained below. Further details are available in the book Business Dynamics by Sterman (2000).

#### Causal Loop Diagram

A CLD helps to describe the feedback dynamics characterising a system. It is composed of variables that are connected by arrows indicating *causal links*, which represent either a positive (+) or negative (-) influence of one variable on another. If such interdependent variables form a closed structure, they are called feedback loops, which can be either positive (reinforcing) or negative (balancing). Some variables within a system do not react to one another immediately. In this case, a delay is indicated in the CLD with the appropriate symbol. Table 3.1 introduces the symbols used in a CLD.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Name</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="V2" alt="V1" /></td>
<td>Negative causal link</td>
<td>The negative polarity indicates that one variable affects another variable in a negative way.</td>
</tr>
<tr>
<td><img src="V2" alt="V1" /></td>
<td>Positive causal link</td>
<td>The positive polarity indicates that one variable affects another variable in a positive way.</td>
</tr>
<tr>
<td>![B-]</td>
<td>Balancing loop</td>
<td>This symbol indicates that the variables interact with one another in such a way that they form a balancing feedback loop.</td>
</tr>
<tr>
<td>![R+]</td>
<td>Reinforcing loop</td>
<td>This symbol indicates that the variables interact with one another in such a way that they form a reinforcing feedback loop.</td>
</tr>
<tr>
<td><img src="V2" alt="V1" /></td>
<td>Delay</td>
<td>This symbol indicates that one variable affects the other variable with a delay.</td>
</tr>
</tbody>
</table>
Moreover, variables can be distinguished between exogenous and endogenous ones. Exogenous variables are not affected by any other variables in the CLD. Even though they are affected by many different variables in real life, the CLD does not take them into account. This is either because it would exceed the scope of the project or they are irrelevant for that specific CLD. Endogenous variables are the ones that are directly affected by other variables.

To fix ideas, basic concepts are explained by referring to the simple CLD in figure 3.1. It gives an example of a CLD in the context of traffic congestion. In this case, the variables of the traffic system are car use, road capacity and congestion.

![Traffic congestion, Road capacity, Car use](image)

**Figure 3.1:** Example of a CLD (own representation based on Shepherd (2014))

A **positive link** means that an increase of variable A leads to an increase of variable B, while a decrease of variable A leads to a decrease of variable B. Considering figure 3.1, a higher degree of traffic congestion would lead to city planners implementing more road capacity expansions than initially planned. Whereas a lower degree of traffic congestion could result in the city planner not taking countermeasures concerning road capacity expansions.

A **negative link** means that if variable A rises, the linked variable B decreases. On the contrary, if variable A decreases, variable B grows. For instance, in figure 3.1, more expansions on road capacity would lead to a lower degree of traffic congestion than usual. At the same time, if fewer expansions on road capacity were implemented, it would lead to a higher degree of traffic congestion than expected.

However, an increase of a variable does not necessarily lead to an increase or decrease of the linked variable. This is because variables are usually linked to a number of other variables. When looking at the example of traffic congestion (see figure 3.1), there is a negative link from road capacity to traffic congestion. But traffic congestion is also influenced by car use, which is positively linked. Therefore, even if road capacity expansions were implemented, traffic congestion would not decrease if car use increased at the same time.

Figure 3.2 highlights in red the two types of feedback loops in the simple CLD previously introduced – one balancing feedback loop (see figure 3.2a) and one reinforcing feedback loop (see figure 3.2b).
3.2 Change Management

The three-step model of change by Kurt Lewin (1947) represents how change can be achieved in a society or an organisation. It is divided into the three steps unfreeze, move and refreeze. Lewin views behaviour as a dynamic equilibrium, where the forces of behaviour work in
opposite directions (Cummings et al.; 2016).

Figure 3.3 illustrates Lewin’s model, of which the steps are further explained in the paragraphs below.

Figure 3.3: Model of change by Lewin (own representation based on Cummings et al. (2016))

**Unfreeze** Unfreezing the current situation is the first step for change (ibid.). Here, people realise that their expectations are not in line with reality (ibid.). They start to question their behaviour and see the necessity for change. This step can be achieved by motivating the people that change is needed and by earning their trust. A brainstorm session to find possible solutions can also help to unfreeze people (ibid.).

**Change** This stage represents the phase of change and moving forward (ibid.). People are persuaded that the current behaviour is not the right one and encouraged to change their perspectives of looking at a problem. In this phase, the changed behaviour is implemented (ibid.).

**Refreeze** The last step of the model of change deals with the topic of refreezing (ibid.). After the change has been achieved, it needs to be ensured that it remains and that people do not move back to their old patterns of behaviour. The new routine needs to be stabilised by making it the new norm. It can be accomplished by reinforcing the new pattern of behaviour and by introducing formal and informal policies to institutionalise it (ibid.).

For this project, Lewin’s model will be used to analyse the possibility of nudging people towards using car alternatives.

To understand the change model clearer, an example is given in the context of a doctor’s practice. Currently, all medical records are written by hand. Even though switching to an electronic format would increase efficiency, the employees show concerns about switching. These concerns can be overcome by using Lewin’s model of change.

**Unfreeze** Firstly, the perceived benefits of the change need to be communicated to the employees. Hereby, the focus lies on demonstrating how the positive aspects outweigh the negative aspects.

**Change** In this step, the new electronic recording system is implemented. This change can lead to fear due to uncertainty whether the new system will be beneficial. Therefore, it is essential to offer training on the new process and for the managers to be communicative towards the employees to counteract this fear.

**Refreeze** In the refreezing step, it is essential to make sure the employees accept the new electronic system as the new norm in order to make them adopt it consequently. Moreover, the efforts made by employees need to be recognised through some reward.

According to Burnes (2004), Lewin was a humanitarian who believed that only by solving social conflicts, the situation for humans can be improved. Therefore, he aimed at facilitating
societal learning in order to enable people to change their views of the world (ibid.). He developed this model as a contribution to organisational and societal change (ibid.).
Chapter 4

Method

In this chapter, the methodology used for conducting the research is explained. Firstly, the overall research design is stated. The two RQs arrange the sections, data collection and data analysis. The section on data collection describes which databases and search terms were used for the literature review as well as how other empirical data were collected. Furthermore, how the collected data for each RQ were analysed is explained in the section data analysis. Moreover, validity and reliability explain how it was ensured that the data collection and analysis were conducted in a reliable manner. Lastly, ethics describes how the research was conducted ethically by abiding laws and ensuring transparency.

4.1 Research design

The thesis looked at this topic with an abductive approach. Therefore, the problem was first stated, and then the relevant theory was searched to obtain a better understanding of which research had previously been done. More literature was found as the investigation progressed. In order to answer the two RQs, a single case study in a suburban municipality close to Munich called Kirchheim bei München (Kirchheim) was conducted. This municipality was chosen because it is highly affected by the city next. A high degree of urban sprawl has been taking place from Munich to its suburbs, which makes it a typical urban-suburban area scenario. The results of the case study made it possible to draw general conclusions for other suburban municipalities with similar characteristics. The single case study was undertaken by looking at secondary data, by collecting primary data through a survey and conducting a literature review.

The methodology for each RQ is separately explained below.

4.2 Data collection

Two similar surveys with two stakeholder groups – daily commuters to and from Kirchheim – were conducted to collect quantitative and qualitative data. These were relevant to answering the RQs. To survey the commuters to Kirchheim, various companies in Kirchheim were selected who received an online survey to distribute to their employees. In order to receive feedback from all employee groups, physical copies were sent to employees who do not occupy office space. When it came to surveying commuters from Kirchheim, the citizens of Kirchheim were an appropriate group. Questions similar to those used for the survey conducted with commuters to Kirchheim were asked. Several locations to conduct the survey in person were selected – the car park of a local grocery store, the train station Heimstetten and several bus stops in Kirchheim. This method made it possible to reach both the commuters who use PT and also those who use private vehicles. The survey was undertaken on a weekday from 03:00 pm to 8:00 pm, which is the time most people commute home from
work. Furthermore, the survey was shared on social media channels and by email to sports clubs in Kirchheim. In both surveys, it was of interest to find out their chosen mode of transportation for their daily commute and to investigate whether they are satisfied with it. It was also assessed which factors play a role for them to be content with their daily commute and whether they would be willing to switch their MoT.

The following paragraphs explain how the data were collected for the specific RQs.

**What are the causes and effects of the increasing strain on the transportation system with their dynamics?** To find out about the causes, historical data of the development in Kirchheim were collected. The relevant data were the job, the demographic and the choice in MoT development. Hereby, some of the data had already been collected previously. Firstly, a household survey with quantitative and qualitative data, for example, on the preferred MoT used, was conducted. It also showed the MoT used for which cause and at which time of day. Moreover, it provided qualitative data on the problems the citizens of Kirchheim face with the current traffic situation. In addition, historical data of improvements to PT and road infrastructure were collected. A literature review of what causes and effects traffic congestion has was also conducted. In order to search for relevant literature, Google Scholar was the first database used and then other databases, such as Science Direct and Springer Link. The search terms are presented in table 4.1 below.

<table>
<thead>
<tr>
<th>Database</th>
<th>Search term</th>
<th>Filters</th>
<th>Hits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Google Scholar</td>
<td>Causes of traffic congestion</td>
<td>since 2015</td>
<td>21,400</td>
</tr>
<tr>
<td>Science Direct</td>
<td>Urban sprawl in Europe</td>
<td>none</td>
<td>5,661</td>
</tr>
<tr>
<td>Springer Link</td>
<td>Suburbanisierung München</td>
<td>none</td>
<td>46</td>
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<td>Google Scholar</td>
<td>Traffic congestion &quot;System Dynamics&quot;</td>
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<td>Traffic congestion caused by housing problem in Europe</td>
<td>since 2015</td>
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<td>Employment effects of road traffic congestion in Europe</td>
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<td>since 2015</td>
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<tr>
<td>Google Scholar</td>
<td>Vehicle emission and air pollution related to driving patterns</td>
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The survey of commuters clarified which factors influence their decision to choose a certain MoT and give insights into how this has led to the current situation.

Not only the causes but also the effects of the increase in strain on the infrastructure needed to be assessed. Therefore, data on air and noise pollution were collected. A sensor for measuring particulate matter (PM) levels PM$_{10}$ and PM$_{2.5}$, which had previously been installed in Kirchheim, helped ascertain the current pollution levels.
PM are tiny for the human eye invisible particles floating in the air, which do not sink to the ground immediately (Umwelt Bundesamt; 2013). Instead, they remain in the atmosphere for a while. During certain weather conditions, a haze dome can be seen if a high PM level is present. \( \text{PM}_{10} \) are all particles with a diameter smaller than 10\( \mu \)m and \( \text{PM}_{2.5} \) are the ones with a diameter smaller than 2.5\( \mu \)m (ibid.).

Previously, another sensor had been installed, of which the historical data were available to compare previous measurements with the current ones. Furthermore, the increase in traffic was of interest. Finally, the commuter surveys provided insights into the happiness level of commuters, which is an effect of the current situation.

**Which solutions are feasible in order to accommodate the increasing strain on transportation infrastructure during peak hours?** First of all, a literature review on which solutions other cities and countries have come up with was conducted. The following search terms and databases were used as illustrated in table 4.2.

<table>
<thead>
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<th>Database</th>
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<th>Hits</th>
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<td>Google Scholar</td>
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<td>since 2015</td>
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<tr>
<td>Google Scholar</td>
<td>Home office to reduce commuter traffic</td>
<td>since 2015</td>
<td>17,200</td>
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<td>Google Scholar</td>
<td>Free public transportation and its effects</td>
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<td>Google Scholar</td>
<td>Road pricing to reduce traffic</td>
<td>since 2015</td>
<td>18,000</td>
</tr>
<tr>
<td>Springer Link</td>
<td>Mobilitätskonzepte</td>
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<td>615</td>
</tr>
</tbody>
</table>

Hereby, the causes of the increasing strain on the transportation infrastructure were used to determine how best to tackle the issue. The two surveys were the primary tool to gather information on the wants and needs of the stakeholders in order to improve the public infrastructure and make their daily commute a better experience. Moreover, it provided an insight into which factors would induce them to switch to more sustainable MoTs. Their expectations of future mobility in Kirchheim were also assessed. This information was essential in the analysis section to ascertain whether conceptual solutions would be accepted by society. The answer to RQ 1 was also relevant in order to conclude with possible solutions.

### 4.3 Data analysis

The following paragraphs explain the data analysis for each RQ separately.

**What are the causes and effects of the increasing strain on the transportation system with their dynamics?** To find out about the dynamics of the causes and effects regarding this topic, the ST approach was used to expand the mental models of linear causes and effects and instead look at traffic dynamics as a whole system with interrelated variables. Therefore, a CLD was created using Vensim software (Ventana Systems, Inc.; 2015) to illustrate how the three variables within the subsystems population, traffic and economy are interdependent. Insights drawn from the literature gave knowledge towards developing the CLD with their variables. The information from the CLD gave insights into which feedback loops might occur by changing one part of the system. It also helped draw the conclusion regarding which variable needed to be modified to reduce traffic congestion in the long term. To create the CLD, the relevant literature reviewed, as well as other empirical data, were
4.4. VALIDITY AND RELIABILITY

Which solutions are feasible in order to accommodate the increasing strain on transportation infrastructure during peak hours? Firstly, the results of the surveys were illustrated in graphs created using Python and the plotting library Matplotlib (Hunter et al.; 2019) to obtain an overview of what expectations the stakeholders have. Moreover, the commuting habits of Kirchheim’s citizens and employees were assessed. When visualising the survey results, the commuters were also grouped by residence and work location to assess feasible solutions depending on their locations.

In a next step, the information extracted from a previous household survey and other historical data served as an insight on how Kirchheim the commuting habits were in previous years and how the municipality developed over time. Lastly, the data collected on conceptual solutions as well as solutions already implemented in other cities and countries from the literature review were used to analyse whether they are the right approach to solving traffic congestion in Kirchheim and suburban municipalities in general.

4.4 Validity and reliability

This study fulfils its purpose by answering the two RQs. The literature section concentrates on gathering data from previous projects on which causes and effects exist on the topic of traffic congestion. In this section, it was important to observe the dynamics within the traffic congestion system. Therefore, a CLD was created to capture the interdependencies of the variables. To avoid favouritism when creating the CLD, most variables were decided on by using the information from the literature review and survey results.

Moreover, the two surveys provided empirical insights into the case study of Kirchheim. This single case study can be classified as an appropriate way of viewing an example of a municipality with traffic problems and analysing the expectations of the stakeholders directly from primary sources. In addition to the causes and effects, the literature review discussed different ways of reducing traffic congestion. This was the foundation for assessing conceptual solutions for suburban municipalities.

When conducting the literature review, peer-reviewed journal articles from official databases were mostly used. Furthermore, the selection criteria and the scope of the project were determined beforehand to avoid bias. The surveys were distributed in such a way as to reach the entire audience of commuters. They were not only distributed indirectly through social media channels but also directly by contacting Kirchheim’s companies and sports clubs and conducting the survey in person in Kirchheim. Even employees in Kirchheim who do not have access to a computer were taken into account by distributing the survey to them in the form of hard copies to ensure a reliable and representative result of the survey.

The results from the single case study can be generalised for all suburban municipalities with similar characteristics as the municipality where the study was conducted. Furthermore, it can be expected that similar results will be achieved if this case study were to be replicated. This is the case because the survey participants selected were chosen in such a way that they represented the commuting society of the municipality.
4.5 Ethics
When distributing and conducting the surveys, care was taken to ensure that they are in line with European data protection law. Firstly, the answers were treated completely anonymously without being able to track the responses back to any particular person or IP address. Additionally, the time at which the surveys were answered was not tracked. Besides, the survey participants were informed about the purpose of the study and participated voluntarily. Moreover, an offer was made to distribute the survey results to the participants after the analysis had been completed. Lastly, the survey results were only used for this degree project.

4.6 Limitations
Bias about how the survey questions are asked (especially when doing an in-person survey)

As stated by Sterman (2002), all SD models are wrong due to several reasons. Firstly, a certain degree of bias is present in each CLD and less experience with modelling them, leads to a higher degree of bias. Furthermore, the in chapter 6.2 presented CLD has included several exogenous variables. Sterman (2002) points out that very few variables can be considered exogenous. He says that even the ones that seem like they have no important interrelatedness with other variables of the system should be included as endogenous variables. He gives the example of weather that seems like an exogenous variable since it cannot be controlled. However, due to climate change, we now know that the weather has been affected by humans. Nevertheless, as treating the exogenous variables as endogenous ones would have exceeded the scope of this project. Therefore, this limitation needs to be taken into consideration when looking at the results.

Lastly, this thesis project generally was limited by time and scope, which is why further research possibilities are pointed out in the conclusion chapter to expand on the knowledge gained through this project (see section 8.2).
Chapter 5

Empirical results

In this chapter, all empirical data gathered in the course of the project are formulated after providing more details about the case study. In particular, the results from the case study conducted are presented. To begin with, the overall results of the commuter survey in Kirchheim are discussed, followed by a summary of the discovered causes of traffic congestion in Kirchheim and their effects.

5.1 Description of case study

In 2018, the Munich Chamber of Industry and Commerce (German: Industrie- und Handelskammer, IHK) came forward and endorsed a Smart Mobility Initiative, which has the objective of evaluating several solutions to cope with the increasing strain on transportation infrastructure using big data. The objective was to be explored by conducting a pilot project in a selected suburban municipality near Munich. The IHK chose Kirchheim bei München (Kirchheim), a municipality with approximately 13,000 inhabitants (2016) since the citizens had previously been proactive and started a citizens’ initiative in 2013 in which a traffic concept was developed (Krause; 2018). In this concept, the issues faced were summarised and various approaches the citizens believed could improve the situation were presented.

The pilot project consists of four work packages (WP). WP 1 aims to evaluate the causes and effects of the traffic dynamics within Kirchheim, which should result in conceptual solutions and is performed in the course of this degree project. The second WP is to introduce commuter buses in Kirchheim by the end of August 2019. WP 3 is a student project that installs traffic counting sensors to detect the hotspots in Kirchheim and WP 4 conducts a traffic simulation of conceptual solutions in the municipality (Fassbender; 2018). WP 1 outlines the thesis project, which then is expanded on by exploiting Change Management and SD modelling.

Industrieanlagen-Betriebsgesellschaft mbH (IABG) is a company located in Ottobrunn near Munich that offers integrated, innovative solutions for various sectors IABG mbH (n.d.). It is a member of the Smart Mobility Initiative and contributes towards the pilot project by conducting the WPs 1 and 2. This work lays the foundation for undertaking future activities involved with the Smart Mobility Initiative, such as the above-mentioned traffic simulation (WP 4).

Kirchheim, the location of the case study, is a municipality within the district of Munich. It is located 12 kilometres north-east of Munich (Gemeinde Kirchheim b. München; 2016) and approximately 20 minutes from Munich’s city centre by train. Around 13,000 citizens live in the municipality and some 7,300 jobs are provided there (Landratsamt München; 2019).
Figure 5.1 shows a map of Munich with the location of Kirchheim north-east of the city highlighted in red.

![Map of Munich with Kirchheim highlighted](image)

**Figure 5.1:** Location of Kirchheim within the district of Munich (Google; 2019)

Figure A.1 in appendix A shows a close-up of the map of the municipality of Kirchheim, which is divided into two districts – Kirchheim and Heimstetten. As the map shows, the municipality is located close to two motorways – the A99 and the A94 (marked by the blue signs). It has access to a train station for services to and from Munich and a bus service also connects the underground train services in Munich. Moreover, two industrial estates are located in Kirchheim and Munich airport is only 30 kilometres away (Gemeinde Kirchheim b. München; 2016). As Kirchheim’s transportation infrastructure is very diverse, commuters have a broad range of MoTs to choose from, which makes it a very interesting location to conduct a case study on traffic dynamics.

The municipality consists of two industrial estates – Kirchheim I in the north-east (highlighted in green) and Kirchheim II Heimstetten in the south (highlighted in red), which are both marked in the map in figure A.2 in appendix A.
Figure A.3 in appendix A shows a map of Munich’s PT network (MVV), which also includes Kirchheim with the train station Heimstetten highlighted in red on the train line S2 in the north-east. The PT services S-Bahn (suburban train), U-Bahn (underground train), regional train and tramway are also presented.

According to a household survey conducted by Baumgärtner (2016), Kirchheim’s inhabitants complain about the noise pollution caused by moving traffic and a lack of soundproofing. They also state that the noise coming from the motorway is an issue for them.

5.2 Household survey

Prior to the IHK endorsing the pilot project initiated by the Smart Mobility Initiative, a household survey had already been conducted in 2015. The survey was distributed to all households in Kirchheim’s municipal district and a total of 1,187 responses were collected, which means a 20% response rate was achieved (Baumgärtner; 2016).

**Commuting habits** The survey responses show that Kirchheim’s citizens (not only when commuting, but when travelling in general) 42.1% travel by car, 19.2% by bicycle and 12.8% by PT. Moreover, 18.1% of people walk and 7.8% form carpooling groups.

**Satisfaction** An open-ended question was also available for Kirchheim’s population to answer, which asked about their opinion on the traffic issues in the municipality.

On the topic of moving traffic, the respondents criticised the high volumes of traffic on the roads Heimstettener Moosweg, St2082, Hauptstraße and Münchner Straße (see figure 5.2 highlighted in green). They also pointed out car drivers speeding and a lack of traffic calming measures on the above-mentioned roads. Moreover, they mentioned the need for a roundabout at the intersection of Heimstettener Moosweg and St2082, also known as the Kirchheimer Ei (see 5.2 highlighted in red). Moreover, they commented on the lack of or poor condition of footpaths and bicycle paths. When talking about the PT infrastructure, the main complaint was the infrequent bus and train service, delays and cancellations.

**Future outlook** Another open-ended question gave the participants the opportunity to make suggestions for improvements.

On the topic of moving traffic, the respondents pointed out that they would like to see better protection measures implemented to combat noise pollution, the construction of more roundabouts, stricter speed limits and a new road surface where needed. Furthermore, they call for the construction of ring roads or other measures to reduce traffic congestion. To improve the situation for cyclists and pedestrians, the participants specify that they require the construction of new and the expansion of existing cycling and footpaths. In addition, they require safer crossing options, such as pedestrian traffic lights, zebra crossings and underpasses. In terms of PT infrastructure and service, Kirchheim’s inhabitants recommend a train service every ten minutes towards Munich, more bus stops and a higher-frequency service in the evenings and on weekends.
CHAPTER 5. EMPIRICAL RESULTS

Figure 5.2: The municipality of Kirchheim with hotspots highlighted (Google; 2019)

5.3 Commuter survey

In the course of this single case study, two commuter surveys were conducted – one involving Kirchheim’s citizens and one for the employees of companies in Kirchheim – from 1 April until 26 April 2019. This was done in order to assess the commuters’ expectations, their wants and also their needs, in order to obtain a better understanding of the current situation and to conclude with conceptual solutions that will benefit the municipality of Kirchheim. It is specifically important to take the expectations of the commuters into account in order to ensure a high acceptance and adoption rate for any solutions implemented in the future.

A total of 261 responses were collected by reaching out to the commuters in different ways. Firstly, the survey was conducted in person by approaching people at the train station in Heimstetten and at bus stops all over Kirchheim. This attempt to survey Kirchheim’s citizens yielded around 20 responses. A further 72 citizen responses were gathered by sharing the survey on social media channels by email with the various clubs and societies in Kirchheim. The 186 responses of employees of Kirchheim’s companies were collected by sharing the online survey by email with the companies’ representatives, who then forwarded it to their employees. Moreover, physical copies to be distributed to employees without an office space were sent to the companies by post. Taking into account both respondent groups ensured that the participants overall represent the society of the municipality of Kirchheim to make sure reliable results are achieved.

Because the surveys, apart from two questions, are the same, the two surveys are treated as one. In the following paragraphs, the survey questions are stated and it is argued why they were of interest for this study. The results of the survey are presented thereafter.
5.3.1 Explanation of survey questions

This section states the survey questions and explains why they were asked. In general, a mix of closed-ended questions, open-ended questions and questions with a Likert scale were provided. A full version of the two commuter surveys – citizens and employees – is attached in the appendix B and can be viewed there.

**General questions**  To begin with, general questions were asked on the one hand to assess whether the respondents represent Kirchheim’s society and, on the other hand, to detect possible habitual differences between various groups, such as age or gender groups. The first questions were put to ascertain the gender and age of the participants. Furthermore, the net income, location of workplace and residence were asked. All of these were stated to find a correlation between the participant characteristics, their chosen MoTs and their willingness to switch to alternative MoTs, just to name a few. Apart from these, a question was asked on whether the participant has underage children in order to find, for example a correlation between chosen MoTs and the need for flexibility.

**Commuting habits**  The second group was question in order to assess the commuting habits of the participants. This was necessary to find out about the chosen MoTs and the reasons for choosing them. Moreover, it was of interest to find out how many respondents among those who drive by car to work own a company car. As stated in the literature review, the option of using a company car is likely to increase the probability of driving. Therefore, this question assessed whether this was the case. The MoTs to select were car, carpooling, bicycle, on foot and PT. If none of the presented MoTs applied to the respondents, they also had the option to select "other" and specify the type of MoT thereafter.

**Satisfaction**  The satisfaction question group was designed to include a Likert scale. Hereby, the response options were strongly disagree, disagree, agree, strongly agree and no statement. The questions were posed to assess the satisfaction concerning, for instance, time, cost, stress and flexibility. The questions that assessed the satisfaction with the duration and the financial cost of the commute served to find out the overall satisfaction of the journey to and from work. To find out whether the commute has psychological effects on each individual, a question whether the commute is experienced as a burden was asked. A question was put regarding the importance of low-emission vehicles was put in order to see the context of sustainability and commuting. To see how many individuals travel with their chosen MoT due to habit or due to conviction, a question on whether they question their commuting habits was placed as well. Moreover, it was of interest to ascertain how many people actually use their time while commuting productively, such as working or reading, because some people might not have the option to choose between different types of MoT. The question on whether the respondent is able to choose between several MoTs was interesting in order to investigate whether people are forced to use certain MoTs or use it for other reasons. Two questions were put with the aim of ascertaining people’s willingness to change their commuting habits. One of the questions asked whether the respondent is willing to pay more in order to save time during the commute and the other was asked to ascertain whether the commuter is prepared to pay more to be more flexible during the commute. These two questions are useful in order to assess whether certain conceptual solutions would be accepted by society in general. Lastly, an open-ended question was placed to discover what general complaints commuters have about their journey.
CHAPTER 5. EMPIRICAL RESULTS

Future outlook This category consisted of two open-ended questions. The first question was asked in order to ascertain what conditions would have to exist to induce the commuter to switch from using the car to an alternative MoT. In the literature review, it was specified that a car uses the most space on the road per person. Therefore, to reduce congestion, reducing car use is of interest, which is why the willingness of the respondents to switch needed to be assessed. This question only appeared for participants who selected the car as their chosen MoT. The second question in the category and also the final question of the survey asked how the respondent would describe their ideal commute. Hereby, the goal was to hear about solutions other cities have implemented and to examine the overall expectations of commuters.

5.3.2 Responses

The responses of the commuter survey are grouped by the question groups named previously – general questions, commuting habits, satisfaction and future outlook.

General questions In total, 278 commuters to and from Kirchheim participated in the survey, of which 261 were fully completed and can be taken into account for the case study. Among the respondents, 3.4% are below the age of 20, 19.2% are between 20 and 29, 31.8% between 30 and 39, 19.9% between 40 and 49, 19.5% between 50 and 59 and 6.1% are 60 or older. The results are shown in figure 5.3a. Moreover, of all respondents 41.1% are women and 58.9% are men as illustrated in figure 5.3b. Among the survey respondents, 40.6% are citizens of Kirchheim’s and 59.4% live in Munich or the surrounding areas of Munich (see figure 5.4a). The employees of companies in Kirchheim were divided into groups of people who work in the industrial estate Kirchheim I, industrial estate Kirchheim II Heimstetten and in other locations in Kirchheim, such as the municipal centre. Figure 5.4b illustrates these findings. Now that the characteristics of the respondents have been presented, it is important to know the commuting habits of these. This is necessary to answer the two RQs in chapter 6. RQ 1 in section 6.1 aims at analysing the causes and effects of the traffic dynamics, for which the commuting habits need to be taken into account. Additionally, for RQ 2 in section 6.2 the willingness of the commuter groups (e.g. age groups, income groups) to switch to alternative MoTs is assessed. Therefore, the empirical results to support the analysis are provided below. Firstly, the general commuting habits are described before assessing the satisfaction of commuters with their daily journey to and from work.

A further analysis on the commuting habits to and from Kirchheim is provided below. There, also the commuting habits are analysed by different groups, such as age, gender, workplace.

Commuting habits When looking at the chosen MoTs in figure 5.5, the proportion of car users (67.7%) stands out. PT is the second-most used MoT. Cycling and walking are the next most often ways chosen to reach work. Since the distances from locations other than Kirchheim are too far for most people to cycle, it is of interest to ascertain the number of people who cycle within Kirchheim. This finding is described in the analysis chapter.

Satisfaction When asking commuters whether they experience their commute as a burden (see figure 5.6a), a very high proportion pointed out that it is burdensome. However, also a very high proportion said that they strongly disagree. Among all respondents, 151 stated that they are either satisfied or highly satisfied with the duration of their commute, while 106 replied that they are unsatisfied and highly unsatisfied. This is visualised in a graph in figure 5.6b. As indicated by the survey, 93 respondents are unsatisfied with the costs of commuting in relation to its quality. However, 153 consider the cost as appropriate (see figure 5.7a). When asking whether commuters use their time productively during their commute, a
very high proportion (192 participants) pointed out that they strongly disagree. Conversely, 73 participants stated that they make good use of their time while commuting, such as reading or working (see figure 5.7b). Figure 5.8a shows that exactly half of respondents pointed out that they are able to choose between different MoTs when commuting. When asked whether the commuters question their commuting habits once in a while, half of them declared that they do (see figure 5.8b). The two subfigures in figure 5.9 show the proportion of commuters willing to pay more to increase flexibility (figure 5.9a) and to reduce the duration of the commute (figure 5.9b). As it can be seen for both scenarios, the view are divided. Around half of commuters are willing to pay more to increase the quality of their commuting experience. In figure 5.10 the importance of choosing an environmentally-friendly MoT is visualised. More than half of respondents replied that they find a sustainable MoT important. However, a significant number of commuters does not think it is of high importance. The figures (figures 5.6 to 5.10) represent the satisfaction of commuters with their commuting experience and also indicate their willingness to switch to alternative MoTs. A deeper analysis of this can be found in chapter 6.2.1.

The most frequent complaints of the respondents regarding their commute were firstly the delays and cancellations of PT and secondly traffic congestion. Hereafter, the complaints concerning the different MoTs are stated in separate paragraphs.

**Public transportation**  Most respondents stated that the delays and cancellations of trains and buses is an issue for them. Some also said that the train service should be offered more frequently than only every 20 minutes. This is because firstly, the trains are overcrowded during rush hours and secondly, if one train is cancelled, the wait for the next one is too long. Moreover, it limits flexibility. According to the respondents, the bus service should also be offered more frequently. Apparently, the buses do not wait for arriving trains at the train station so that a long wait occurs quite often. The high cost of the PT ticket was pointed out as well. The price-performance ratio does not seem appropriate. For some distances, the commute takes considerably longer by PT than by car. One suggestion to improve the train service was to put in place an express train that stops in Heimstetten.

**Car**  The most frequent complaint of commuters by car was traffic congestion due to construction works and too many cars on the road. Poor traffic light settings were also pointed out as one reason for the congestion. Three hotspots were named – Kirchheimer Ei, A99 and the road that passes the high school in Kirchheim. Some respondents also mentioned the number of cyclists occupying space on the roads.

**Bicycle**  The main complaint of commuters by bicycle is the lack of cycling paths. Without cycling paths the commute is not only more dangerous, cars and buses are also disrupted by cyclists occupying space on the roads. Many people would like to see a cycling path that runs all the way to their workplace and also to other destinations, such as schools.

**On foot**  Most respondents only walk in order to change MoT and therefore did not point out any issues. Similar to statements made by local citizens, a high number of employees point out the time lost due to traffic congestion and inappropriate traffic light settings when commuting by car.
CHAPTER 5. EMPIRICAL RESULTS

Figure 5.3: Age and gender distribution of participants

Figure 5.4: Residence and workplace distribution of participants
5.3. COMMUTER SURVEY

Figure 5.5: Chosen MoT

![Mode of transportation chart](chart)

Experience commute as a burden

![Experience commute chart](chart)

Find duration appropriate

![Find duration chart](chart)

(a) Experience commute as a burden  
(b) Satisfied with duration

**Figure 5.6:** Proportion of commuters who experience commute as a burden and are satisfied with the duration of the commute
CHAPTER 5. EMPIRICAL RESULTS

(a) Appropriate cost of commuting

Figure 5.7: Proportion of commuters who find cost of commuting appropriate and use their commute productively

(b) Use time productively

Figure 5.8: Proportion of commuters who have the choice between different MoTs to commute and who doubt their commuting habits once in a while

32
5.3. COMMUTER SURVEY

(a) Pay more to increase flexibility

(b) Pay more to reduce duration

Figure 5.9: Proportion of commuters willing to pay more to increase flexibility and to reduce duration of commute

Figure 5.10: Importance of a low-emission MoT
5.4 Causes of traffic congestion in Kirchheim

This section describes the various causes of traffic congestion identified in Kirchheim. First of all, the prospering economy has led to many people moving to the suburbs. This can be seen by the demographic and commuter traffic development in the municipality. Furthermore, an increase in vehicle ownership can be observed.

5.4.1 Urban sprawl

The Munich Metropolitan Region (MMR), is an attractive place to settle down. It has a good job market and at the same time offers a high quality of life. Hence, the population has grown significantly and with it the area’s economy. However, the growth in population needs to be facilitated, such as with appropriate housing. Due to the fast growth, the construction of new housing is not sufficient, which has led to a drastic increase in housing prices. Hence, people relocating to Munich have to move to more suburban areas of the region. To put this trend into context, the population, economic and housing development in Munich from 2009 until 2017 is explained below.

Information from a report by Deutsche Bank and written by Möbert (2019) states that between 2009 and 2017, 56,600 new residential units were built, creating accommodation for 100,000 citizens. However, at the same time, the population of Munich rose by 180,000 from 1.36 million to 1.54 million. Since an average of 1.7 people live in a household in Munich, there was a lack of approximately 40,000 residential units in Munich in 2017. When taking into account the increase of single-person households, the housing shortage is even greater. On top of the housing shortage, the employment market in Munich grew by approximately 3% in 2017. This means living costs in general are higher than in other cities in Germany, making, Munich the most expensive city in the country. In 2018, the housing price per square metre outside the city centre stood at 6,790 euros and the increase in housing prices per year are approximately 6.5%. This means Munich was ranked 6th on the European housing market in 2018. In 2017 and 2016, the city ranked 7th and 14th among the most expensive cities to live in Europe. By 2022, Munich’s population is expected to have risen to around 1.7 million and hence, for the incoming 150,000 citizens, 90,000 flats need to be provided. Since in 2017 the city was already short of 40,000 units, 130,000 units will be needed in total. By the year 2035, the population is predicted to be at 1.85 million. Therefore, prices on the housing market are unlikely to stagnate in the years to come. Table 5.1 visualises the previously discussed population increase and the affected housing shortage.

Table 5.1: Population development and housing demand in Munich (Möbert; 2019)

<table>
<thead>
<tr>
<th>Years</th>
<th>Population increase</th>
<th>Housing demand</th>
<th>Housing supply</th>
<th>Housing shortage</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009 - 2017</td>
<td>180,000</td>
<td>100,000</td>
<td>56,600</td>
<td>40,000</td>
</tr>
<tr>
<td>2018 - 2022</td>
<td>150,000</td>
<td>90,000</td>
<td></td>
<td>90,000</td>
</tr>
<tr>
<td>2023 - 2035</td>
<td>150,000</td>
<td>90,000</td>
<td></td>
<td>90,000</td>
</tr>
<tr>
<td>Total</td>
<td>220,000</td>
<td></td>
<td></td>
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As a result of this housing shortage, many people can no longer afford to live in Munich or cannot afford their desired standard of living. Hence, they choose to move to more suburban areas. Therefore, the need for mobility has increased for people commuting from the suburban areas to the city, resulting in longer distances to commute. Moreover, the suburban area is not sufficiently equipped with PT amenities or the frequency of them is not sufficient. This leads to many people commuting by car (Kinigadner et al.; 2016).
5.4. CAUSES OF TRAFFIC CONGESTION IN KIRCHHEIM

The next section (5.4.2) is closely linked to the current one as the urban sprawl in the MMR described above can be ascertained by the population increase in Kirchheim.

5.4.2 Demographic and job development

During the past 30 years, the population of Kirchheim has gradually increased from approximately 11,000 inhabitants in 1987 to approximately 13,000 inhabitants in 2017 and the population is forecast to grow to 15,000 by 2034 (Breu et al.; 2018; Krause; 2018). For a municipality an area of 15.51 km$^2$ (Gemeinde Kirchheim b. München; 2016), this means the population density is likely to increase from currently 840 to 970 citizens per km$^2$. Figure 5.11 shows the gradual growth in population.

![Demographic development](image)

**Figure 5.11:** Demographic development in Kirchheim from 1987 to 2034 (Breu et al.; 2018; Krause; 2018)

A clear trend can be seen when looking at the age distribution. In 1987, the proportion of pensioners stood at 5%, of children and teenagers at 26% and of the working population at 69%. The number of pensioners gradually increased to 24% in 2017 while the number of children and teenagers has dropped since 1987, but recovered again and slowly been increasing to 17% in 2017. The amount of people of working age has slowly decreased from 69% in 1987 to 59% in 2017. Even though the population has grown over time, the working population has not. However, the pensioned population has increased by 1,000 since 1987.

The number of employees in Kirchheim has increased by 1,000 in the last ten years, a growth rate of 15.2% (Breu et al.; 2018). Even though the number of jobs has increased, the ratio of jobs occupied by Kirchheim’s inhabitants and commuters has not changed significantly. Most of the jobs, around 91%, are occupied by commuters and 9% by inhabitants. With a working population of 7,500 in Kirchheim (2017), of which only 700 work in their own municipality, it indicates a high number of people commuting out of Kirchheim. Furthermore, with a number of 7,100 employees in Kirchheim from outside the municipality, it also
indicates a high number of people commuting to Kirchheim (Breu et al.; 2018).

**Figure 5.12:** Job development in Kirchheim from 2007 to 2017 (Breu et al.; 2018)

To see whether the findings of the job development are in line with the assumption that with it also the commuting traffic has increased, it is of interest to examine the commuter traffic development.

### 5.4.3 Commuter traffic development

In total, Kirchheim’s public infrastructure needs to accommodate 11,500 commuters every day. Figure 5.13 shows the development of commuters between the years 2007 and 2017, which has generally risen over the years. The increase in commuters to Kirchheim can be traced back to the job development in Kirchheim. Moreover, the number of people commuting from Kirchheim to can be led back to urban sprawl occurring in the MMR (see section 5.4.1). However, when looking at the commuter traffic development, we need to distinguish more detailed between the commuter traffic to Kirchheim and from Kirchheim. Between 2007 and 2017, the commuter traffic to Kirchheim increased significantly from 6,200 to 7,100 daily commuters (Breu et al.; 2018). Given that the number of jobs increased by approximately the same number, it can be expected that most newly created jobs are occupied by people from outside of Kirchheim. This assumption can be proven when looking at figure 5.14a. The number of commuters within Kirchheim only increased by 100 from 760 to 860 people. Also the number of commuters coming from Munich did not change drastically. It rose by 170 people from 1800 to 2070 commuters (ibid.). People travelling form other places increased more significantly by around 500 commuters during this time (ibid.). Moreover, commuter traffic from Kirchheim increased from 3,800 to 4,300 daily commuters (Breu et al.; 2018) as illustrated in figure 5.14b. The number of commuters travelling to Munich increased slightly by 100 people from 2200 to 2300 commuters. Moreover, the number of people commuting form Kirchheim to other places than Munich increased by 200.
5.4. CAUSES OF TRAFFIC CONGESTION IN KIRCHHEIM

The two plots of commuter traffic development in figure 5.14 show that a clear increase in people commuting has been taking place throughout the previous years, which can be assumed to have impacted traffic congestion.

(a) Commuter traffic development from Kirchheim  (b) Commuter traffic development to Kirchheim

Figure 5.14: Commuter traffic development from and to Kirchheim from 2007 to 2017 (own representation based on Breu et al. (2018))
In a next step, it is of interest to see whether the vehicle ownership has also increased over the years to know whether a higher number of commuters has also led to a higher number of people owning a car.

### 5.4.4 Vehicle development

Since the year 2012, the number of cars in Kirchheim has increased by 1,000 from around 10,000 to 11,000 in 2017. On average back in 2012, every adult owned 1.12 vehicles and to be more specific 0.95 cars. Since then, the proportion has increased slightly to 1.21 vehicles and 1.03 cars per person (in 2017). (Krause; 2018). Figure 5.15 illustrates the increase in car ownership over time.

As car ownership has clearly increased over the years, it can be assumed that this is partly caused due to the increase in commuting distance described in section 5.4.1. Moreover, the job development shows that newly available jobs were not taken by Kirchheim’s citizens. Additionally, the result from the survey exposed that the mostly used MoT is the car. Therefore, it can be expected that these are the reasons for an increase in car ownership.

![Car ownership development](image)

**Figure 5.15:** Car ownership development from 2012 to 2017 (own representation based on Krause (2018))

### 5.5 Effects of traffic congestion in Kirchheim

In the following, the effects of traffic congestion identified by the empirical findings are presented. Firstly, the economic effects, then the environmental effects and lastly, the psychological effects are pointed out.

#### 5.5.1 Economic effects

As mentioned in chapter 2.2.1, traffic congestion is said to reduce employment growth in an area. However, Kirchheim is a strong economic location, where several successful companies are located in the two industrial estates and the town centre of the municipality that provide
around 7,300 jobs in total. Additionally, it is easy to reach the municipality by PT and car due to the transportation infrastructure provided (Gemeinde Kirchheim b. München; 2016). Additionally, a constant increase in the number of jobs in Kirchheim can be observed, which leads to the conclusion that no severe negative effects of traffic congestion on the economy can be identified.

5.5.2 Environmental effects

This section names the effects on the environment and, more specifically, the air quality and noise pollution in Kirchheim.

**Effects on air quality**

According to Umwelt Bundesamt (n.d.a), the yearly average PM$_{2.5}$ value should not exceed 25 µg/m$^3$. Moreover, the daily average PM$_{10}$ value is not allowed to exceed the limit of 50 µg/m$^3$ more than 35 times per year and the yearly average value needs to be below 40 µg/m$^3$. Umwelt Bundesamt (n.d.b) states that the nitrogen dioxide measurements in Europe are not allowed to be higher than an hourly average of 200 µg/m$^3$. This limit must not be exceeded more than 18 times per year. The yearly average limit is determined at 40 µg/m$^3$. However, a yearly average value of 30 µg/m$^3$ is recommended for environmental protection reasons.

Between 31 December 2013 and 31 December 2014, a temporary air quality sensor was installed in Kirchheim near the motorway A99 close to Tegernseestraße to measure particulate matter PM$_{10}$. During these 12 months, nitrogen dioxide NO$_2$ was also measured for 14 days. The measurement of NO$_2$ was done by means of diffusion tubes (passive collector). This method works by absorbing the NO$_2$ in the air onto wire gauzes coated with triethanolamine. Then, in a laboratory, the nitrogen dioxide value is determined by ion chromatography after elution with high-purity water. The PM$_{10}$ values are determined by collecting the fine dust particles using an active volume flow regulated collection system in accordance with the PM$_{10}$ sampling convention (DIN EN 12341). For this purpose, a quartz fibre filter produced by the company Piper Filters was used (InfraServ Gendorf GmbH; 2015). The report on air quality states that the defined daily average PM$_{10}$ value was exceeded once during the time frame of 12 months. However, this was on New Year’s Day, which can be explained due to fireworks used to mark the occasion. The yearly average PM$_{10}$ value was measured at 13 µg/m$^3$. Moreover, a yearly average NO$_2$ value of 31 µg/m$^3$ was measured (ibid.).

On 23 February 2018, a low-cost air quality fine dust sensor Nova Fitness SDS011 was installed at a height of 2.7 metres on a quiet road in a residential area in Kirchheim. It uses the technology of laser scattering, which can detect particulate matter between 0.3 to 10µm in the air and is therefore, appropriate to measure PM$_{2.5}$ and PM$_{10}$. It works most accurately at a relative humidity between 25% and 50% with a relative error of maximum ±15% and 10µg/m$^3$ (Eckstein GmbH; n.d.). Dynamic data of the measurements taken from this fine dust sensor can be used to analyse the air quality in Kirchheim. Figure 5.16 shows that the daily average PM$_{2.5}$ measurements in Kirchheim varied (Luftdaten.info; n.d.). The yearly average from 24 February 2018 until 23 February 2019 was 10.3 µg/m$^3$ and therefore below the limit (ibid.). Figure 5.17 shows the daily peak PM$_{10}$ measurements recorded in Kirchheim. The red line in the figure indicates the daily average limit of 50 µg/m$^3$. From 24 February 2018 to 23 February 2019, the PM$_{10}$ measurements exceeded the limit 12 times (Luftdaten.info; n.d.). The yearly average during the same time frame was 15 µg/m$^3$. The dates when the measurements were extremely higher than usually are on 1 January, which
can be explained due to New Year’s Even celebration. Moreover, the PM$_{10}$ are only reliable at a relative humidity between 25% and 50%. Therefore, dates where measurements are a lot higher than usual, can be misleading. Nevertheless, the results of both PM$_{2.5}$ and PM$_{10}$ during the time frame show that the air quality in Kirchheim is in accordance with European standards and has no direct health effect on the population.

**Figure 5.16:** Daily average PM$_{2.5}$ measurements in Kirchheim since February 2018 (own representation based on Luftdaten.info (n.d.))

**Figure 5.17:** Daily average PM$_{10}$ measurements in Kirchheim since February 2018 (own representation based on Luftdaten.info (n.d.))
Effects on noise pollution

Traffic noise limitations in Germany differ for newly built and existing roads. The limits are shown in table 5.2 below.

<table>
<thead>
<tr>
<th>Type</th>
<th>Time of day</th>
<th>Limit (new)</th>
<th>Limit (existing)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hospitals</td>
<td>Day time</td>
<td>57 dB(A)</td>
<td>67 dB(A)</td>
</tr>
<tr>
<td>Schools</td>
<td>Night time</td>
<td>47 dB(A)</td>
<td>57 dB(A)</td>
</tr>
<tr>
<td>Residential areas</td>
<td>Day time</td>
<td>59 dB(A)</td>
<td>67 dB(A)</td>
</tr>
<tr>
<td></td>
<td>Night time</td>
<td>49 dB(A)</td>
<td>57 dB(A)</td>
</tr>
<tr>
<td>Nursing homes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Town centres</td>
<td>Day time</td>
<td>64 dB(A)</td>
<td>69 dB(A)</td>
</tr>
<tr>
<td>Villages</td>
<td>Night time</td>
<td>54 dB(A)</td>
<td>59 dB(A)</td>
</tr>
<tr>
<td>Mixed areas</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Industrial estates</td>
<td>Day time</td>
<td>69 dB(A)</td>
<td>72 dB(A)</td>
</tr>
<tr>
<td></td>
<td>Night time</td>
<td>59 dB(A)</td>
<td>62 dB(A)</td>
</tr>
</tbody>
</table>

A noise protection assessment for the district of Munich conducted under the authority of Landratsamt München (2015) resulted in the following findings for Kirchheim. In the day time, the area around the motorway A99 and the federal highway St2082 showed noise levels between 60 and 75 dB(A). Other roads in the centre of the municipality, such as Hauptstraße, Räterstraße, Heimstettener Moosweg and Felkirchner Straße, reach noise levels of 60 to 65 dB(A). The motorway A99 and St2082 were assessed with noise pollution levels of up to 75 dB(A).

During the night, the A99 still reaches noise levels of up to 75 dB(A). St2082 has noise levels of up to 70 dB(A). Based on the noise assessment, the roads A99, St2082 and Feldkirchner Straße were identified as conflict roads in the municipality of Kirchheim (Landratsamt München; 2015). At the time of the assessment, the following noise protection measures were in place.

<table>
<thead>
<tr>
<th>Road type</th>
<th>Road name</th>
<th>Max. speed</th>
<th>Type of measure</th>
<th>Status of measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorway</td>
<td>BAB A99</td>
<td>130 km/h</td>
<td>Noise protection wall</td>
<td>Partly constructed</td>
</tr>
<tr>
<td>Municipal road</td>
<td>Ammerthalstr.</td>
<td>50 km/h</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>District road</td>
<td>Poinger Str.</td>
<td>30 km/h</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Municipal road</td>
<td>Räterstr.</td>
<td>30 km/h</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>District road</td>
<td>Münchner Str.</td>
<td>50 km/h</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Municipal road</td>
<td>Heimstettner Str.</td>
<td>30 km/h</td>
<td>Noise protection wall</td>
<td>Constructed</td>
</tr>
<tr>
<td>District road</td>
<td>Erdinger Str.</td>
<td>30 km/h</td>
<td>None</td>
<td></td>
</tr>
</tbody>
</table>

Landratsamt München (2015) suggested installing the following additional noise protection measures. The motorway BAB A99 should be equipped with a low-noise road surface as well as noise protection walls. A tunnel or a bypass should be built to reduce traffic congestion on St 2082. Furthermore, traffic laws should be changed so that no heavy-duty traffic is
allowed to enter Kirchheim at night. Lastly, the traffic light settings should be set in a way that they are need-oriented (ibid.).

5.5.3 Psychological effects

Among the 249 respondents of the commuter survey (that answered the specific question), 143 (57.4%) pointed out that they experience their commute as a burden that negatively affects their well-being. This indicates that the current traffic situation in Kirchheim and Munich highly reduces the quality of life of those affected. Figure 5.6a illustrates this fact. In order to find out more about the consequences these psychological effects have on the society, more research needs to be conducted.

Moreover, the noise measurements described in the section above (5.5.2), show that in certain areas the noise pollution is above the set limits, which can lead to psychological health effects from an allostatic overload.

5.6 Implemented measures in Kirchheim

In order to facilitate using the bicycle for short distances within the municipality, a bicycle concept has been developed, of which the following measures have been implemented to date. All dead-ends, which are possible to pass through by bicycle have been equipped with signs. A bicycle street has been identified on Bajuwarenstraße between Josefstraße and Heimstettener See. Additionally, protective strips have been dedicated for cyclists on Erdinger Straße and Feldkirchener Straße. A cycling highway is under development in the corridor Munich – Markt Schwaben. Furthermore, from now on, the cycling paths will be cleared from snow in winter. All in all, cyclists are more supported by the municipality by providing the area with two bicycle repair machines, more bicycle racks and clearer signpostings (Cullen; 05-April-2019).
Chapter 6

Analysis

The analysis of RQ 1 is approached by exploring the issue of traffic congestion and analysing the dynamics of causes and effects using SD. Developed conceptual solutions from insights of the answer of RQ 1 as well as literature and empirical data are explained in the analysis of RQ 2.

Since most of the data were collected by conducting a case study in Kirchheim, the RQs are answered by referring to this municipality. Kirchheim is located within the district of Munich and is highly affected by the city. Therefore, many conclusions drawn from the city of Munich can be transferred to Kirchheim. How the results of the analysis can be generalised for suburban municipalities is described later on in chapter 7.

6.1 Research question 1 – Traffic dynamics

What are the causes and effects of the increasing strain on the transportation system with their dynamics?

Traffic congestion in suburban areas is an issue that needs to be tackled sooner rather than later. However, this is not an easy task because of the dynamic nature of the problem. The causes of traffic congestion and their effects cannot be investigated in a linear way. In fact, several interrelated variables come into play, which form feedback loops. A proper tool to investigate complex dynamics of variables in a system is the CLD. And therefore to answer RQ 1, a CLD of different endogenous and exogenous components of the traffic congestion has been created to analyse the interdependence of these. For further details on SD and in particular CLD, more information is provided in chapter 3.1.2.

The CLD in figure 6.1 was created using Vensim software (Ventana Systems, Inc.; 2015) and visualises the relevant variables characterising the traffic system of a suburban municipality. In particular three subsystems have been identified: population, economy and traffic. They do not only consist of variables that refer to the suburban area, but also the urban area. This is because many characteristics in the suburban area are consequences of the urban area. It is highlighted in the figure which area the variable represents. If nothing specific is mentioned, the variable represents both areas.
6.1.1 Subsystems

To understand the CLD, firstly, the three subsystems population, economy and traffic with their endogenous and exogenous variables are explained before describing causal links that interconnect them and form feedback loops.

Population subsystem

The population subsystem shows the citizens’ dynamics in the suburban area and is represented by the endogenous variables suburban population, emigration and immigration.

The suburban population indicates the number of people living in Kirchheim. It can also refer to other suburban municipalities around Munich, since they are similarly affected by the city. Immigration and emigration represent the number of people moving to and away from Kirchheim.

Economy subsystem

The economy subsystem is represented by the endogenous variables housing prices in the suburban and urban area, two-income households and environmental pollution. Moreover, the exogenous variables of public investments, economic growth in the urban area and modern culture are included.

The housing prices in the suburban area and housing prices in the urban area determine the cost of buying or renting accommodation in these places, which contributes highly to living expenses. Modern culture describes the cultural change that has occurred in recent years. It used to be the case that women stayed at home to take care of the household and

Figure 6.1: CLD of traffic dynamics in a suburban municipality
6.1. RESEARCH QUESTION 1 – TRAFFIC DYNAMICS

children. However, this cultural change has led to a higher number of women wanting to make their own career. Since analysing all the factors that have emphasised this change in culture would exceed the level of details of this thesis, this variable was treated as an exogenous one. Talking of cultural change, this leads to the variable two-income households variable expresses the fraction of households in which both spouses are employed. Public investments are mainly considered for investing in road capacity expansions or mind shift policies towards using car alternatives. It is classified as exogenous because investing in public projects often involves numerous stakeholders, which are external to the system, such as at federal, state, city or municipality level. Public investments might even be affected by the degree of economic growth in the surrounding area. Nonetheless, these details can be revealed by future work. Economic growth in the urban area serves to represent components such as the employment rate, companies’ turnover and in general, how well the economy in the MMR is performing. Moreover, urban economic growth is considered to be an exogenous variable in line with the level of detail chosen for this work. Economic growth in the suburban area is a consequence of the urban economy, since many people work in Munich and companies in the suburbs benefit from a well-functioning economy in the city. Therefore, the variable of suburban economic growth has been omitted and only urban economic growth is taken into consideration.

Traffic subsystem

The traffic subsystem includes the endogenous variables road capacity, traffic congestion, car use, travel demand, environmental pollution and mind shift towards using car alternatives.

The road capacity specifies the maximum number of vehicles the road infrastructure in Kirchheim can handle and the variable car use determines the number of cars that are actually on the roads. The variable traffic congestion can be described as the number of cars on the roads with respect to road capacity. In other words, the more the cars on the roads reach the road capacity limits, the more they are stuck in traffic. Travel demand indicates how much the people want and need to commute. Lastly, mind shift towards car alternatives explores the option of changing the mindset and habits of commuters in order to use options other than the car for their daily commute. When describing environmental pollution, the degree of air and noise pollution in the urban area caused by traffic is referred to.

6.1.2 Feedback loops with causal links

After explaining the meaning of variables in the CLD, the causal links between them are described with their polarity (i.e. positive or negative influence) so that the feedback loops can be identified. Feedback loops show the interdependencies of variables and how they indirectly affect themselves. Six feedback loops have been identified in the CLD in figure 6.1:

- Population decrease
- Creating congestion
- Population increase
- Solving congestion with infrastructural investments
- Creating congestion with infrastructural investments
- Solving congestion with service investments
The loop \textit{population decrease} visualises what effects the housing prices have on emigration. Secondly, \textit{creating congestion} determines how an increase in travel demand leads to congestion. Moreover, \textit{population increase} shows how the suburban population increases and how it affects the environment. An approach to \textit{solving congestion with infrastructural investments} is visualised as well as how it leads to a rebound effect in a feedback loop \textit{creating congestion with infrastructural investments}. A final solution on how to achieve a long-term reduction in congestion is shown by presenting the feedback loop \textit{solving congestion with service investment}.

\section*{Population increase in Kirchheim}

The five variables that play a main role towards dynamics of population increase are: Kirchheim’s population, travel demand, car use, environment and immigration. Figure 6.2 illustrates this reinforcing loop. Additionally, housing prices in the urban area, two-income households, economic growth and modern culture further influence the population increase in suburban areas.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{pop_increase_cld.png}
\caption{CLD of traffic dynamics with highlighted \textbf{population increase} feedback loop}
\end{figure}

In order to understand this feedback structure, the causal links are explained below.

\textbf{Immigration $\rightarrow+$ suburban population} The positive polarity of immigration to suburban population shows that the more people move to Kirchheim, the larger the population in the municipality grows.

\textbf{Suburban population $\rightarrow-$ travel demand} Travel demand is the variable that connects the economy and population subsystems with the traffic subsystem. Most of all, the travel
demand is impacted by the number of people living in the suburban area as they need to travel to their workplaces, which are mostly located in the city.

**Travel demand** \(\rightarrow\) **car use** The higher the travel demand, the more people tend to use cars for their commute. The commuter survey indeed showed that the car is the most frequently used MoT.

**Car use** \(\rightarrow\) **environmental pollution** Vehicle emissions have a negative impact on the environment and contribute towards greater environmental pollution, as does traffic noise.

**Environmental pollution** \(\rightarrow\) **immigration** When the pollution in the MMR becomes unbearable and threatens the health of the population, many people might be driven towards moving to a more suburban area such as Kirchheim.

**Economic growth** \(\rightarrow\) **urban housing prices** Housing prices are affected by economic growth. Improved economic development means that more people can afford living in the urban area, as working and living in Munich is an advantage. This leads to an increased demand for housing. If the demand is not satisfied by available housing, the housing prices increase.

**Urban housing prices** \(\rightarrow\) **immigration** Urban housing prices have a positive polarity towards immigration to the suburban area. In other words, the higher the housing prices in Munich, the more people prefer moving to suburban municipalities such as Kirchheim in which housing prices are still lower than in urban areas.

**Urban housing prices** \(\rightarrow\) **two-income households** Higher housing prices increase the number of two-income households since higher living expenses make it necessary to have a higher household income. Therefore, in many families both spouses need to work to afford living expenses.

**Economic growth** \(\rightarrow\) **two-income households** Not only higher costs of living, but also a well-functioning economy establishes an increasing number of households with two incomes. This is the case because economic growth also leads to a higher employment rate.

**Modern culture** \(\rightarrow\) **two-income households** Apart from the two factors mentioned before, a cultural change can also lead to a greater number of two-income households, as many women want to have their own career. A number of factors have contributed to this more modern culture, such as the higher level of women’s education.

**Two-income households** \(\rightarrow\) **travel demand** When more people are employed, more people also need to travel. Furthermore, it is difficult to find accommodation that ensures that both working people in a family can live near to their workplaces, which might be far away from each other. Hence, the commuting distance increases and with it also the need to travel.
To sum up this reinforcing feedback loop, it can be said that vehicle emissions from the perpetually increasing car use contribute towards a higher level of environmental pollution in the city. People who want to live in an area with high air quality and low noise pollution might prefer moving to a suburban area such as the municipality of Kirchheim. The physical and psychological effects of noise and air pollution mentioned in section 2.2.2 should not be underestimated. Another factor contributing to people willing to live in the suburbs is the constantly increasing housing prices in Munich. This is the fact because the economy in Munich is prospering and economic growth has accelerated in recent years. Hence, many people simply cannot afford to live in the city and move to more suburban areas, where housing prices are lower. In turn, the population in the suburban area including Kirchheim grows, which raises the travel demand of people, as most companies are located in Munich. Therefore, people employed in Munich need to commute from the suburban area to the city on a daily basis. Another factor contributing to the higher travel demand is the inflation of living costs in Munich, which has given many families no other alternative than to establish a double-income household, in which both spouses have a job. Nevertheless, not only the higher cost of living can lead to two-income households. Pfaff (2014) mentions the cultural aspect of emancipation and the demand of women to make their own career. Regardless of the reasons, an increasing employment rate has caused the travel demand to increase, as it is difficult to find a house that is close to both spouses’ places of employment. Therefore, the average commuting distance has increased significantly in previous years, partly for this reason, which also raises the car use accordingly.

The next two sections 6.1.2 and 6.1.2 show feedback loops that are balanced out by the dominating feedback loop mentioned in the current section.
Population decrease in Kirchheim

Figure 6.3 highlights in red the feedback loop *population decrease in Kirchheim* consisting of the three variables: population, suburban housing prices and emigration.

![Diagram of traffic dynamics with highlighted population decrease feedback loop]

In a first step, the causal links are described before moving on to explaining the feedback loop.

**Suburban housing prices** →+ **emigration** In this CLD, emigration is positively affected by high housing prices in Kirchheim. This means higher housing prices might make the area less attractive or affordable to live in, which could lead to a number of people emigrating. Through this causal link, the population subsystem influences the economy subsystem.

**Emigration** →- **suburban population** A higher number of people moving away from Kirchheim and migrating to other areas leads to a lower number of people living in Kirchheim.

**Suburban population** →+ **suburban housing prices** A higher population in Kirchheim raises the housing prices in the municipality. This is the case because the demand for housing rises and the housing prices rise accordingly.

To summarise, the **balancing feedback loop** of a decrease in population emphasises that when housing prices in the suburban area rise, an increasing number of people are unable to afford the living expenses in this area or their desired standard of living cannot be met by their income. Hence, these people decide to move to more affordable areas, which leads to a population decrease in Kirchheim. However, a reduced population in Kirchheim will eventually impact the housing prices in the municipality negatively. This described scenario shows
that this is a balancing feedback loop. Nevertheless, this feedback loop cannot compete with the immigration flow coming from Munich, which constantly increases the population in the suburban area and does not allow the housing prices to stagnate. As most companies are located in Munich, and housing prices are even higher there, a lot of people do not have the option to move from the suburban area to the urban area. Moreover, it is impossible for most people to move from the suburban area to more remote places because otherwise their workplaces (in the city) might no longer be accessible. Therefore, many people do not have the option to move away from the suburban area and have to accommodate the high housing prices by for example lowering their housing standards. This statement can be understood more clearly when referring to section 6.1.2.

### Congestion dynamics

Figure 6.4 presents the feedback loop that comprises the variables congestion, emigration, suburban population, travel demand and car use. It explains how direct cause and effect dynamics of traffic congestion follow a closed causality structure.

![Figure 6.4: CLD of traffic dynamics with highlighted creating congestion feedback loop](image)

**Suburban population** $\rightarrow+ \text{ travel demand}$ and **Travel demand** $\rightarrow+ \text{ car use}$

These two causal links have already been explained in section 6.1.2.

**Economic growth** $\rightarrow+ \text{ car use}$  This thesis considers urban economic growth as directly affecting car use, since more well-paid jobs lead to a higher standard of living. Hence, more people can afford owning a car and are willing to pay more for their commute. The results of the commuter survey show that the level of income affects the amount of people driving to work by car up to a certain extent (see figure 6.6b).
Car use $\rightarrow+$ traffic congestion  As explained above, traffic congestion is caused by too many cars and too little maximum road capacity. Hence, the higher the car use, the greater the traffic congestion.

Traffic congestion $\rightarrow+$ emigration  A high degree of congestion makes an area unattractive to live in, due to the noise and air pollution and also the lacking of convenience to travel because of traffic jams. Therefore, traffic congestion could lead to a higher number of people moving away from this area.

Emigration $\rightarrow-$ Suburban population  This causal link has already been explained in section 6.1.2).

As already stated in section 6.1.2, a higher population in suburban areas means that more people need to travel and also that the distances they need to travel increase in order to reach the city from the suburbs. This demand to travel leads to increased use of transportation. The commuter survey found out that the most chosen MoT is the car. Therefore, higher travel demand leads to increased car use, which results in a higher degree of traffic congestion. The dissatisfied suburban population might decide to migrate to places other than the suburban area, such as the city, and results in a balancing feedback. Even though a lower suburban population would decrease the travel demand, this is unlikely to happen as housing prices in Munich are expected to continue increasing until 2035, which would make many people unable to move, even if they desired. Therefore, the balancing feedback is overruled by the population increase feedback loop and hence, is ineffective. For a more detailed explanation of how housing prices in the city affect the suburban area, refer to section 6.1.2.

The following two sections refer to feedback loops already described in the CLD example presented in chapter 3. Therefore, the reader can refer to the description in section 3.1.2 for more details.

Solving congestion by investing in infrastructure

Infrastructural investments are usually made to expand the road capacity with the attempt to solve traffic congestion. Below, the causal links between the endogenous variables congestion and road capacity and the exogenous variable public investment are briefly explained before describing the respective feedback loop (see figure 3.2a).

Congestion $\rightarrow+$ road capacity  Congestion is the main factor towards road capacity expansion because city planners to expand invest in infrastructure projects in order to accommodate the constant traffic increase.

Public investment $\rightarrow+$ road capacity  In order to finance capacity expansions, public investments are made.

Road capacity $\rightarrow-$ congestion  The more cars a road can carry, the less congestion occurs, since congestion is caused by too many cars having too little maximum road capacity.

This balancing feedback loop attempts to reduce traffic congestion by expanding the road capacity. Usually, when a high level of traffic congestion exists in an area, city planners invest in public infrastructure projects for the road capacity, such as building ring roads or new tunnels. The new capacity is said to decrease congestion, but the following section clarifies why this solution does not actually solve congestion in the long run.
Increasing car use due to new infrastructure

As shown in figure 3.2b, the higher attractiveness to drive on less congested roads results in a **reinforcing feedback**. Before going more into detail, the causal links are described.

**Car use \(\rightarrow\) congestion & Congestion \(\rightarrow\) road capacity** The impact of car use on congestion has been pointed out in section 6.1.2 and the positive polarity of congestion to road capacity has already been described in section 6.1.2.

**Road capacity \(\rightarrow\) car use** The higher the road capacity, the more car use increases because driving becomes more attractive. This usually happens with a delay, which makes it difficult to identify as it is not an obvious effect of road capacity expansions.

Even though expanding the road capacity seems like an appropriate measure in the first place, the **reinforcing feedback loop** shows that merely building new infrastructure does not solve the issue of congestion. The construction works take a long time, are expensive and the road capacity is usually reduced at this location during the time of construction. Moreover, even though road capacity is increased after construction is completed, car use also increases after some time because more space on the road means driving is more enjoyable. Therefore, expanding road capacity, as described in section 6.1.2, is only a short-term solution and leads to a vicious cycle.
Solving congestion with service investment

Instead of investing in road capacity expansions, which lead to a vicious cycle and do not effectively solve traffic congestion problems, public investments in services that promote alternative ways to commute might be more effective. In fact, new services could help change the mindset of people in a way so that commuters do not choose the car anymore as the best option to travel. The balancing feedback loop approaches this is highlighted in figure 6.5.

**Figure 6.5:** CLD of traffic dynamics with highlighted solving congestion feedback loop

The causal links are explained below.

**Public investment →+ mind shift towards car alternatives**  The variable of mind shift explores the alternative to break out of the vicious cycle of increasing traffic congestion by providing alternatives to using the car, hence reducing car use. To finance these, public investments in car alternatives need to be made that lead to this mind shift.

**Congestion →+ mind shift towards car alternatives**  In addition, to public investments, the more traffic congestion there is in Kirchheim, the more a mind shift towards using car alternatives expected, as driving becomes less attractive the more traffic jams occur.

**Mind shift towards car alternatives →- car use**  When a mind shift towards using alternative MoTs occurs, it might reduce the number of people using cars, or they might choose other MoTs for certain journeys, such as for their commute. This happens because people are more aware of the consequences of car use on the traffic and more convenient options are available to accommodate their need to travel.
Car use $\rightarrow+$ congestion  As mentioned previously, higher car use increases the degree of congestion. Conversely, however, lower car use decreases the degree of congestion.

This reinforcing feedback loop makes it possible to break out of the vicious cycle of increasing congestion by reducing car use in the long run. Short-term investments aimed at achieving the mind shift can be improving the service, such as more frequent PT services or improving bicycle infrastructure. Long-term investments can be, for example, expanding the railway network. Even though this expansion has a low cost benefit in the short run, it is a long-term solution without the rebound effect of increased car usage.

The CLD presented was created based on the insights drawn from the literature available of the causes and effects of traffic congestion. Observing the dynamics between the interrelated variables of the CLD has been used as a tool for analysing the dynamics of the causes and effects of traffic congestion. The feedback loop dynamics investigated in this section provide a solid answer to RQ 1. It has led to the conclusion that simply expanding road capacity cannot solve the issue of traffic congestion in the long run. Instead, car use needs to be reduced. With this point in mind, many different solutions from the literature review seem feasible in order to achieve a reduction in car use. For instance, improving the PT service enhances its attractiveness, which might lead to an increase in PT usage. Moreover, a habitual change needs to take place in order to convince commuters that using the car is not the best option. In this regard, an analysis of which solutions are feasible to reduce car use is available in section 6.2.

6.2 Research Question 2 – Conceptual solutions

Which solutions are feasible in order to accommodate the increasing strain on transportation infrastructure during peak hours?

When explaining the dynamics of the causes and effects of the traffic system in chapter 6.1, it was pointed out that in order to improve the traffic situation, simply expanding road capacity will not ease congestion in the long run. In this case, the result would be a vicious cycle of a reinforcing feedback. Therefore, expanding road capacity will not be further dealt with as a conceptual solution.

In the following paragraphs, conceptual solutions that can be implemented without reinforcing feedbacks are presented after analysing the responses of commuters.

When asked how commuters imagine their perfect commute, the following criteria were pointed out most frequently. Many people pointed out that they wish for direct routes when using PT without having to change MoTs. Moreover, they specified that they want PT to be more reliable and more flexible. A high number of respondents also said that they wish for less traffic congestion on the roads. Lastly, some participants mentioned that they desire PT to be as fast as driving.

Solutions to reduce car use lead to less congestion. As mentioned in chapter 2.1.1, at a speed of 30 km/hour, a car with the average amount of occupancy (1.4 passengers) requires 65m$^2$ per person (Randelhoff; 2015). A bus or a train with 20% occupancy makes better use of the land with an area of 8m$^2$ and 5m$^2$ per passenger. Therefore, a strategy to reduce congestion in Kirchheim could be to make commuters switch from using a car to a more space-saving MoT (ibid.).
6.2.1 Chosen MoTs

As revealed in the commuter survey, 68% of commuters drive to work by car (see figure 5.5 in chapter 5.3.2). However, in order to reduce congestion, it is essential to reduce car use. If commuters switched from using the car to PT, carpooling or other alternatives, it would have a huge impact. This way the land use per passenger could be reduced as pointed out in section 2.1.1. Investments to reduce car use can both be solutions that need a long and a short period to be implemented. Firstly, the short-term solutions are discussed. However, before doing so, the reasons to why commuters choose the car and which characteristics car drivers have need to be analysed. Therefore, the choice of MoT is presented in different distributions, e.g. age, income level.

Figure 6.6a shows the age of commuters grouped by chosen MoT. The proportion of car users is the highest among people above the age of 40. This can be interpreted as a change in mindset towards a more sustainable lifestyle in the younger generation. Possibly, the people below 40 cannot afford owning their own car due to the high cost of living in the MMR and a lower income than the older generation. Another factor that comes into play is that the older people are, the more likely they are to be physically handicapped. The proportion of car drivers below 20 is the lowest, since most of them do not own a car or have a driving licence.

It is also necessary to find out whether the choice of MoT depends on the level of income. Figure 6.6b visualises the income groups with their MoT choices. A prominent rise in car use can be detected until a monthly net income level of 4,000 euros. Surprisingly, the car use decreases above an income of 4,000 euros. Possibly, the income is only relevant up to a certain extent. When a high enough income level is reached, where daily activities are covered, a hassle-free commute is preferred.

It is, moreover, of interest to see whether the preferred MoT is different according to workplace location or place of residence to detect whether a certain MoT is chosen more frequently because of a lack of infrastructure or service.

Figure 6.7a shows the chosen MoTs are distributed by workplace location in Kirchheim. Kirchheim I is the industrial estate in the north-east of the municipality and Kirchheim II is the industrial estate in the south of the municipality in Heimstetten. It is visible that the chosen MoTs are distributed quite equally among the different workplace locations. Car use is with around 60% the most frequently used MoT among the locations. The bicycle is used more often in the industrial estate Kirchheim I and other locations in Kirchheim. It is less used among people commuting to the industrial estate Kirchheim II Heimstetten, but instead the employees there use PT more frequently, which can be explained since the train station is located right next to the industrial estate and can hence, be reached more comfortably.

However, it is quite the contrary when looking at the places of residence people commute from, the choice of MoT varies significantly among the locations. Figure 6.7b shows a bar chart with the amount of people commuting to and from the different locations. It is relevant to see whether the supply of MoT service and infrastructure affects the choice of MoT. The bar Munich shows Kirchheim’s citizens who commute to Munich and Munich’s citizens who commute to Kirchheim. The bar Kirchheim shows Kirchheim’s citizens who also work in the municipality and Kirchheim’s citizens who commute to the surrounding areas of Munich. Citizens of the surrounding areas of Munich who commute to Kirchheim are represented.
by the bar around Munich. First of all, the high proportion of commuters by car in all groups needs to be pointed out (67%). Moreover, the bar chart shows that more people who commute from the surrounding areas of Munich use the car than people who live or work in Munich and Kirchheim. This can be explained because the frequency of PT might be insufficient or no PT is available. People are dependent on using the car. The number of Kirchheim’s citizens who also work in the municipality taking the car is also quite high (25 of 33 people). However, a high number also travel by bicycle. The highest number of PT users commute to and from Munich, which can be reasoned as the PT service offers the best coverage in the urban area. Nevertheless, many commuters still choose to travel by car (50 of 104 people).
6.2. RESEARCH QUESTION 2 – CONCEPTUAL SOLUTIONS

(a) Grouped by commuter age

(b) Grouped by income

Figure 6.6: Chosen MoT grouped by age and income

(a) Grouped by location of workplace in Kirchheim
(b) Grouped by location of residence and workplace

Figure 6.7: Chosen MoT grouped by location of residence and workplace
Satisfaction of MoT

In order to find out whether the commuters are willing to switch to alternatives of car use, their satisfaction of their current chosen MoT needs to be assessed. Walking is not taken into consideration for this section as it is mostly only used for changing MoT and not for the whole commute.

Figure 6.8a shows how many people believe that their commute affects their well-being depending on their chosen MoT. Overall, independent of MoT, a high proportion of commuters think that their commute has a negative effect on their well-being (see figure 5.6a). This is in line with the literature that says that commuting in general lowers the life satisfaction (see chapter 2.2.2). It is significant that cyclists find their commute the least of a burden. This matches again with the insight from literature referred to in chapter 2.2.2, which states that cyclists are the happiest among commuters. Moreover, cycling can be seen as a free-time activity that also fulfils the need to reach the workplace. Therefore, commuting does not seem that much of a burden. A high proportion of commuters by PT and car find their daily commute as burdensome, which can be explained by traffic congestion and unreliable PT services.

The graph in figure 6.8b shows the satisfaction of the commute grouped by MoTs. Users of PT services are the least satisfied with the duration of their commute. This can be explained by the constant cancellations and delays of trains pointed out by commuters. Also commuters by car are rather unhappy with the duration. Again, traffic congestion could be the issue. Cyclists seem to also be unsatisfied with the duration of their commute as well, which could be because cycling is not as fast as driving a car for example.

In figure 6.9a the satisfaction with the cost-performance-ratio is illustrated. A high number of PT users pointed out that they are mostly satisfied with the costs. The monthly ticket for the MVV is rather cheap compared to driving by car. The proportion of cyclists satisfied and unsatisfied is almost the same. Whereas commuters by car are the least satisfied with the cost-performance-ratio. Firstly, petrol is expensive in Germany and secondly, due to traffic congestion, the commute takes long and is troublesome. This leads to a high degree of overall unhappiness with the commute.

As expected, PT users use their commuting time the most productively as they do not need to concentrate on driving for example. They can easily work or read while sitting on the train. This is also the reason why commuters by car are the least productive while driving. The small proportion left could be them listening to an audio book or the news for instance. Figure 6.10a indicates the number of commuter who can choose between several MoTs. This is of interest since the people who have the choice could be easily nudge to switching from using the car to another MoT. Almost half of the car drivers point out that they do not have the option of another MoT. This leads to the conclusion that they drive because they have to in order to reach their workplace. An even higher proportion can be seen for the other MoTs.

When looking at the number of people that question their commuting habits (see figure 6.10b), it is clear that overall, around half of commuter question their commute once in a while. It might be possible to nudge the other half of respondents to switch to an alternative MoT if different techniques mentioned below (see section xxx) were to be used.

Among all commuters, around half of them are willing to pay more to increase flexibility as it can be seen in figure 6.11a. There are similar results for the question if commuters are willing to pay more to decrease the duration of their commute (see figure 6.11b). Nevertheless, this means that around half of commuters in general are willing to pay more for their commute if the quality of the service improved.
6.2. RESEARCH QUESTION 2 – CONCEPTUAL SOLUTIONS

Figure 6.8: Proportion of commuters who experience commute as a burden and are satisfied with the duration of the commute grouped by MoT

Figure 6.9: Proportion of commuters who find cost of commuting appropriate and use their commute productively grouped by MoT
**CHAPTER 6. ANALYSIS**

- **(a)** Choice between different MoTs
- **(b)** Questioning commuting habits

**Figure 6.10**: Proportion of commuters who have the choice between different MoTs to commute and who doubt their commuting habits once in a while grouped by MoT

- **(a)** Pay more to increase flexibility
- **(b)** Pay more to save time

**Figure 6.11**: Proportion of commuters willing to pay more to increase flexibility and to reduce duration of commute grouped by MoT
Reasons for car use

As found out in RQ 1, reducing car use would lead to a significantly lower degree of traffic congestion on the roads. Therefore, this section attempts to find out how to make commuters switch from using the car to alternative MoTs. Consequently, it is necessary to assess why so many people use the car. Firstly, the reasons by the overall respondents are explained before naming them for each location. At 69%, the highest proportion of car drivers do so to save time. This could be because the PT infrastructure in Munich is set in a way that it is necessary to switch MoTs frequently. Moreover, you often need to travel to the Munich city centre to switch MoT because the PT is structured this way. Figure A.3 in the empirical results chapter visualises the MVV network. *Flexibility, comfort and insufficient PT* also seem to be strong aspects that speak for commuting by car. Not much flexibility is present for commuting to Kirchheim by PT as the suburban trains go every 20 minutes. This can be an issue if you for example have children and need to leave suddenly due to an emergency. Moreover, the trains are often cancelled, delayed or overcrowded, which shows the missing comfort as well as flexibility. The lack of PT can on the one hand be explained by referring to the infrequent train service. Moreover, some places in the industrial estates are not sufficiently equipped by bus stops. The factors *costs, safety and sustainability* do not seem to be very relevant to commuters. Costs could be less relevant as commuting usually happens on a daily basis and takes up a major portion of time per day. Therefore, keeping the duration short and ensuring enough amount of flexibility and comfort could be more important to commuters than to save costs. The same can be explained for the little relevance of sustainability. Even though one tries to keep the carbon footprint low, this is usually only done to a certain extent up to how much the individual is willing to reduce their own daily comfort. Since Munich, in general, is a very safe place with a low crime rate which is why the topic of safety is usually not on the agenda of people there.

In a next step, the reasons for commuting by car depending one location commuters are coming from or going to in order to detect differences and to detect a potential pattern. The areas to be assessed are Kirchheim, Munich and the area surrounding Munich

### Reasons for car use – Kirchheim to surrounding area of Munich & Surrounding area of Munich to Kirchheim

At around 70%, *time* and *flexibility* are the two most relevant criteria for the 128 commuters who travel to or from the surrounding areas of Munich on a daily basis (see figure 6.12b). This can be explained as in the section before. Since the commute takes place usually twice every day, commuters want to reduce the duration as well as be able to leave from work or go to work at any time, in other words be flexible. Since the PT network is not very present in parts of Kirchheim as well as more remote areas, the high selection of *insufficient PT* can be justified. *Comfort* (43%) was also a very frequent response and can be reasoned by referring to the paragraph above (see paragraph 6.2.1).

### Reasons for car use – Kirchheim to Munich & Munich to Kirchheim

When looking at the responses of people commuting in and out of Munich for work reasons, *time* and *flexibility* are again the most relevant aspects that speak for commuting by car. However, with a percentage of 30 to 40, they are not as relevant as for people in the surrounding areas of Munich. This can be reasoned as the distance from Munich to Kirchheim is only 12 kilometres (see section 5.1). *Comfort* (26%) also seems to be less relevant than compared to the surrounding area. Nevertheless, it still plays a big role on why people commute by car. The biggest difference to the responses of the surrounding area is the percentage chosen for *no or insufficient PT*. Only 22% of car drivers name the lack of PT as a reason for them choosing
the car. This is the case because the PT network in Munich is much better connected in the city compared to the suburbs (see figure A.3).

**Reasons for car use – Kirchheim to Kirchheim** Among Kirchheim’s citizens and at the same time employees, *comfort* (17%), *flexibility* (15%) and *time* (14%) are the most important aspects of commuting by car. The same as for the other location groups, this can be justified by taking into account that the commute takes place every day and the need for a comfortable, flexible and short commute outweighs the other factors. *Insufficient PT* hardly influences their choice in driving by car. This shows that enough PT is available in Kirchheim, but does not seem to give enough flexibility and comfort and it takes too long.

After breaking down the reasons for using the car for each commuter group, the bar chart in figure 6.12a shows that time, comfort and flexibility are the most important aspects for all of them. Mostly in the surrounding area of Munich, but also in Munich itself, a lack of PT plays a big role for them to drive to work by car. Therefore, in order to make them switch to alternative MoTs, the above mentioned factors need to be addressed. Especially in Kirchheim, where PT does not seem to be lacking, commuters still choose the car. This emphasises that not the lack of PT is the problem, but the lack of its efficiency is.

The commuters with underage children need to be taken into consideration as well, since a higher degree of flexibility is usually needed. For example, it is possible that the child suddenly gets sick and needs picking up from school or the parents need to drop off and pick up children from school or nursery at different times. Figure 6.14 shows that commuters with children use the car for their commute more frequently than the ones without children. The number of cyclists and people who walk is almost the same for both groups. This can be explained as most people who walk or cycle to work live close to their workplace. However, this is further analysed in section 6.2.1. A lower proportion of parents travel by PT. This can be led back the complaints of commuters on the lack of reliability of Munich’s PT services.

The need for using a car because of having underage children should not be forgotten. In fact, 35% of commuters by car have underage children (see figure 6.14). Additionally, the proportion of people with underage children is higher among people who commute by car than by any other MoT. This can be explained by the need to be more flexible and having to drop off and pick up children from nursery, school and other places. For parents to use PT therefore, frequent and reliable PT services are needed.

The sections below examine ways of achieving that more people use alternative MoTs than the car. Chapter 6.2.2 names ways realising this by improving the PT service. As demanded by the survey participants, 6.2.3 discusses how improving the bicycle infrastructure and service can achieve a modal shift. Moreover, in section 6.2.4 what a higher occupation of car use can achieve by introducing ride sharing is analysed. Not shifting MoT, but avoiding commuting completely is spoken of in section 6.2.5. A way to nudge people by introducing different pricing techniques is talked about in section 6.2.6. As spoken of in the literature review, section 6.2.7, examines an approach to build a mobility hub in Kirchheim and finally, section 6.2.8 points out the futuristic solution of exploiting the third dimension with air taxis.
6.2. RESEARCH QUESTION 2 – CONCEPTUAL SOLUTIONS

Figure 6.12: Reasons for commuting by car

(a) Reasons for commuting by car

(b) Reasons for commuting by car to and from the surrounding area of Munich

Figure 6.13: Reasons for commuting by car to and from Munich and Kirchheim

(a) To and from Munich

(b) To and from Kirchheim

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6.2.2 Improve PT service

One way of nudging people into switching their MoT could be to improve services to provide better alternatives to using the car. When asking the survey participants what would need to change for them to switch from using the car to another MoT, a high number of them replied that a more frequent and reliable PT service would persuade them to switch. The PT service can be expanded by implementing more frequent PT services and also new bus routes. This way, delays and cancellations of PT will not have as big an impact as they have now, since another bus or train will come shortly after. This is specifically useful in Kirchheim, as the most often mentioned complaints about the PT service in the municipality were delays and cancellations of trains and the infrequent bus service. Thereby, the perception of PT can be boosted and commuters are more likely to switch. The survey showed that around half of the surveyed commuters either do not or hardly ever question their commuting habits. This information provides insight that many commuters might not switch from using the car to another MoT because of their prevailing mindset. Consequently, different approaches to changing habits can be used. One of them is to implement fare-free or low-cost PT for a short period of time to nudge people to use PT. This method has already been tested in several cities, as mentioned in the literature review. In all places tested, PT usage increased during the trial phase. After reverting to the previous fares, PT usage was still higher than before. This fact led to the conclusion that a change of habits was achieved by nudging. However, it should be noted that not only implementing free PT increases its usage, but its quality also needs to be adapted considering its reliability, frequency and availability to meet the demand. Therefore, only specified PT service expansions and fare-free PT together can lead to increased PT usage. Long-term fare-free PT is also an option if sufficient budget is available. A test in Tallinn showed that PT usage in general increased significantly. However, the number of cars on the roads did not decrease significantly, which shows that many people who used to walk switched to using the bus instead (Cats et al.; 2017). How-

(a) Chosen MoT
(b) Comparison with other MoTs

Figure 6.14: Proportion of commuters per MoT with and without underage children
ever, a relatively low number of car drivers switched. It should also be noted that, since only Tallinn’s citizens benefited from this subsidisation, quite a few people moved to the city, which led to a population increase. As known from the CLD in chapter 6.1, a higher population is likely to increase congestion.

Some respondents also complained about the cost of the monthly ticket for using the Munich PT network (MVV). The MVV is segmented into different price zones and Kirchheim is located at the edge of two zones, which raises the ticket prices significantly. Many commuters do not find the higher prices appropriate. Hence, one suggestion is to adapt the ticket prices accordingly. However, calculating the feasibility of this measure exceeds the scope of this work and should be conducted in the future. Nevertheless, the city of Munich is discussing the introduction of a yearly ticket for the whole MVV network that only costs 365 euros annually (Gerl; 2019). The subsidisation would counteract the complaint of tickets being too expensive, but not decision has been reached so far.

### 6.2.3 Improve bicycle infrastructure and service

A cyclist uses 41m$^2$ of space on the road and cycling therefore does not seem like an appropriate alternative to achieve less land use. However, if bicycles have a designated area to use, such as bicycle streets and cycling paths, 65m$^2$ (the space a car uses per person) are saved on the road per car user switching to cycling. Hence, first of all, the incentives for using a bicycle need to be raised and the bicycles also need to be accommodated by providing designated cycling routes. Especially Kirchheim’s citizens who also work in the municipality could be targeted to switch to cycling. Moreover, offering on-demand rental bicycles at the train station could be used as a way of targeting commuters from Munich to switch to PT and then use a bicycle for the last mile. This way, no time is wasted on waiting for the bus at the train station. This statement is also in line with the opinion of Kirchheim’s citizens and commuters. The main reason not to use the bicycle was pointed out as a lack of safety because bicycle are either old or do not yet exist. As the municipality has already implemented some improvements for cyclists, the proportion of bike riders is expected to increase.

### 6.2.4 Introduce ride sharing

A higher number of commuters from the surrounding area of Munich specified the insufficient or non-existent PT service as a reason to drive to work. It is understandable that expanding the PT service or infrastructure might not be feasible in sparsely populated areas. Therefore, one solution could be to decrease land use per passenger in cars by increasing the occupation in those vehicles. Ride sharing services, such as Uber or DriveNow, can be used to form carpooling groups. They can also be organised privately by offering an appropriate platform to share the work and residence locations and find people whose locations match. Moreover, commuter buses could be introduced in areas where larger numbers of people en route need to commute to Kirchheim.

### 6.2.5 Introduce telecommuting

The number of car users does not necessarily need to be reduced by making them switch to alternative MoTs, but rather commuting in general could be reduced or omitted by enabling more employees to work from their homes. If working from home is not an option for some as they fear of a lack of productivity or do not have the space for an office in their home, it could also be possible to allow them to work in a co-working space close to their home. This way, the work atmosphere created by leaving the house and working in an office is the case at the same time as reducing the commuting distance. For this reason, the municipality of
Kirchheim could consider creating a co-working space in the area.

6.2.6 Pricing techniques
Pricing techniques other than implementing low-cost or fare-free PT were also looked at in the literature review. Road pricing on certain roads in Kirchheim is another measure that could nudge people not to drive by car. Additionally, parking within the municipality and at company car parks could be charged for to make driving more expensive than it already is. If any of the above-mentioned pricing techniques are implemented, PT services and bicycle infrastructure should be improved and put into place to accommodate the increasing demand.

6.2.7 Mobility hub
Mobility hubs are a way of centralising mobility services and making them more convenient to use. Firstly, information on all mobility services could be presented at one location to make it easier to decide which mobility service to use. Moreover, changing MoTs is less inconvenient because the services are coordinated with one another. One ticket for all services could be provided, which not only saves costs for the user, but also makes them more transparent. Since one ticket also pays for all MoTs, some less popular or sometimes unnoticed MoTs are more likely to be used, as well. The train station in Heimstetten appears to be an appropriate location for a small version of a mobility hub. Bike sharing, car sharing, bus and train services and car parks could all be located at one spot. This way, a convenient inter-modal commuting route could be created. Additionally, with agreement by the MVV, this mobility hub could be integrated in the MVV ticketing system. However, the definition of technologies and agreements should be implemented would exceed the scope of this thesis and can be decided in a future project.

6.2.8 Air mobility
Air taxis and other forms of aerial mobility seem like an applicable way of reducing car use. After all, today’s infrastructure is not equipped to facilitate this futuristic MoT and cannot be considered as a conceptual solution at the present time.

6.2.9 Change Management
Not only implementing these conceptual solutions but also ways of changing the mindset of people can be used to achieve a mind shift towards using car alternatives. The approach of habitual change in was briefly pointed out in chapter 2.3.2 as a way of nudging people to use PT. Therefore, the topic of habitual change in society is further discussed by using Lewin’s model of Change Management introduced in section 3.2. The model consists of the three steps unfreeze, move and refreeze. This section attempts to find a way to nudge people and especially commuters to switch to car alternatives by exploiting this model.

Unfreeze
Many people do not realise that they are part of the bigger problem of traffic congestion which is why awareness for their contribution toward traffic needs to be raised. A habitual change by society can only be achieved by educating people that traffic congestion is reduced by lowering car use and that they can directly impact this change. Consequently, the benefits of reducing car use need to be made clear as well as pointing out that they outweigh the downsides. When introducing one or more of the conceptual solutions discussed earlier, it needs to be communicated clearly that they are beneficial for society and should be adopted. However, not only communication is the key but also the implementation needs to improve travelling for the users in practice. As pointed out by the surveyed commuters, they wish
for PT to be as fast as travelling by car. Therefore, when introducing innovative solutions such as mobility hubs, free PT or ride sharing this aspect should be considered. Moreover, ensuring a high degree of flexibility, comfort and an acceptable price-performance ratio is important.

**Move**

In this stage the change of moving towards car alternatives becomes real. The society’s mindset changes and new behaviours begin to be accepted. At this point, an increasing number of people switches to the implemented solutions either through regulations or because their mindset has changed. Since the newly introduced transportation solutions can result in some uncertainty whether they are beneficial and will not lead to a decreased amount of flexibility and other factors, it is essential to communicate their use very clearly. This leads to a higher adoption rate. Additionally, enough time for this adoption needs to be provided because a habitual change does not occur from one day to the next.

**Refreeze**

The last step of the change process concentrates on solidifying the new state after the change. The new travelling behaviours need to become the new norm so that they are stabilised. This way, society will not move back to the old norms. It can be achieved by rewarding people for not travelling by car, such as with tax exemptions. It could even occur that car use becomes something society looks down on due to the negative impact on traffic and also air and noise pollution. However, this is an assumption that cannot be proven at this stage. All in all, the main goal of decreasing traffic congestion is to reduce car use. This can be achieved by expanding and improving the PT infrastructure, introducing ride sharing services and improving the conditions to cycle for short distances. Another way of nudging people towards cycling for short distances is to implement road pricing and charging for parking in the municipal centre. Moreover, long-term projects, such as introducing a mobility hub and a co-working space in Kirchheim should be considered.
Chapter 7
Discussion

This chapter discusses the results and analysis of the two RQs separately. Moreover, possible limitations of the method chosen for each RQ are stated.

7.1 Research question 1 – Traffic dynamics

What are the causes and effects of the increasing strain on the transportation system with their dynamics?

The analysis of RQ 1 took the causes and effects of the increasing strain on transportation infrastructure into account. Therefore, the discussion is divided into these two headings.

7.1.1 Causes of traffic congestion

The household survey and commuter survey resulted that the highest proportion of commuters travel by car. Moreover, the CLD indicated that a direct contributor to traffic congestion is car use. Indirectly, the population in the suburban area also contributes towards congestion. This is because the more people travel to the city for work, the more cars are on the roads. Among the 7,500 people of working age that live in Kirchheim, only 700 work in the municipality. Therefore, the remaining 6,800 commute on a daily basis to the city or other places. Additionally, the almost 8,000 jobs offered in Kirchheim need to be filled. As only 700 of Kirchheim’s inhabitants work in the municipality, it can be assumed that the remaining 6,800 jobs are filled by people commuting from Munich or other areas. This can also be seen when looking at the historical data on commuter traffic development to and from Kirchheim. While the number of commuters to Kirchheim from within the municipality remained constant, the commuters from other areas increased by 1,000 from 2007 to 2017. Moreover, when looking at the commuter traffic development from Kirchheim, it is visible that the people commuting to other places than the municipality increased significantly between 2007 and 2017.

In this case study, Munich strongly affects the suburban municipality of Kirchheim. Therefore, as Munich’s population has increased significantly during the past years and housing prices have risen, urban sprawl took place and people moved to the suburban area of the MMR. This can also be detected when looking at the demographic development in Kirchheim. Currently, 13,000 people live in the municipality compared to 12,000 in 2007 and 11,000 in 1987. Moreover, the population is said to grow to 15,000 inhabitants by 2034.

This development can also be detected in the increase in car and vehicle ownership. In 2012, on average every citizen in Kirchheim owned 0.95 cars, which increase to 1.03 cars in 2017. It can be assumed that this development has been taken place due to the increase in
7.2. RESEARCH QUESTION 2 – CONCEPTUAL SOLUTIONS

commuting distance. Moreover, since a high number of the survey respondents pointed out that they do not choose PT due to its unreliable service. The survey also showed that most commuters to and from Kirchheim choose the car, which supports the assumption that this has influenced the car ownership development.

7.1.2 Effects of traffic congestion

Even though it is said that traffic congestion reduces employment growth, this effect could not be identified in Kirchheim as the number of jobs has grown constantly in the last decade (see section 2.2.1). Nevertheless, this is an assumption since it is not clear if the job market had grown even more if congestion had been avoided. For this reason, more research needs to be done by for example comparing the economic growth in other suburban municipalities.

More than half of commuters to and from Kirchheim pointed out that their commute affects their well-being negatively. Information extracted from the literature shows that commuting itself affects life satisfaction negatively and the longer the commute takes and the less comfortable it is, the higher the psychological effects are. Consequently, measures to reduce the stress of commuting should be introduced. Commuter buses that directly take the commuters to work or mobility hubs that make changing MoTs less stressful, are measures that could be considered.

As referred to in the literature review in section 2.2.2, the environmental effects of traffic need to be taken serious and need to be counter-measured if they exceed the governmental limits. However, the values extracted from fine dust sensor installed in Kirchheim prove that neither the PM\(_{2.5}\) nor PM\(_{10}\) values exceeded the officially set limits. However, the level of noise pollution in some areas exceeds the limits regularly. Some measures to counteract the noise pollution need to be installed as pointed out in section 5.5.2.

7.2 Research question 2 – Conceptual solutions

Which solutions are feasible in order to accommodate the increasing strain on transportation infrastructure during peak hours?

As found out in the analysis of RQ1, reducing car use is the key to reducing traffic congestion in the long run. Many solutions that could achieve this were discussed. However, only complementary solutions can be successful to reduce congestion. For example, fare-free PT will not make people switch to PT without an appropriate quality of its service. A certain degree of comfort needs to be provided for commuters.

7.2.1 Conceptual solutions

The solutions assessed in this thesis are the following.

One way of nudging people towards using car alternatives is by improving PT services and infrastructure. Since it is now clear that improving the road capacity does not reduce traffic congestion, a higher priority should lie on PT expansions instead of new road constructions. This would highly encourage people towards shifting to PT. If then PT was made more affordable than using the car, this could increase the attractiveness of PT even more.

Improving the bicycle infrastructure and services by building cycling paths and offering bike sharing services is another option to make short-distance travellers switch towards using the bicycle. Even though bicycles use a lot of space, but offering cyclists a dedicated space would avoid the issue of too much land use. Nevertheless, switching to bicycles is only adequate
for short distances and for people without physical disabilities.

Instead of switching to car alternatives, the occupancy of cars can be increased as well by offering ride sharing services. This way, fewer cars are on the road and hence, less space is used by them per passenger. Additionally, cars constantly on the move and do not occupy parking spaces, which can then be used for other facilities.

By offering employees the option of telecommuting, it can highly reduce the need to travel. This way, employees can work from home or another place close to their house, which reduces the travel distance significantly. Another option could be to develop a co-working space in several places, where people can go to work and experience the office environment.

A hard measure to make people reduce their car use can be various pricing techniques that make driving more expensive. Hereby, an increase in taxes on cars, making petrol more expensive, charging higher for parking or introducing road pricing are just a few of many possible measures. It needs to be assessed whether those are relevant for the specific municipality. Moreover, it also needs to be ensured that not only the low-earning society suffers from this increase in cost. There are also pricing techniques that can be seen as soft measures, such as reducing the cost of using car alternatives. This can motivate society to use alternative MoTs.

Since switching from one MoT to another during one journey can be time-consuming, a way of centralising them is of interest as well. A mobility hub, where many facilities are provided like various types of MoT, shops and a nursery, can make the commute more smooth. There, all information should be provided centrally as well as digitally so that only one ticket needs to be purchased and all departure times and so on are easy to be accessed. Moreover, high capacity vehicles can be better utilised so that their occupancy is increased because their departure times can be adjusted to other vehicles’ departure times. However, even though centralising mobility services seems like a measure that will make commuting more efficient, it needs to be pointed out that it also makes the infrastructure more prone to failures. This is because if one MoT or another part of the mobility hub breaks down, it might affect the whole transportation system. This needs to be considered when deciding to implement a mobility hub.

The topic of air mobility was also briefly mentioned. Travelling in the air is an adequate way of reducing car use. However, the downside of it is that in the long run, the more affordable travelling by plane will become, the higher the demand for it will be. This will lead to the same result as with traffic congestion in the long run. Therefore, it can only be seen as a short-term solution.

### 7.2.2 Change Management

Since the thesis discussed the habitual change of society and not of an organisation, some differences between the two groups need to be pointed out when applying Change Management. When companies introduce a change, usually employees are convinced by the change through applying various change management techniques. The goal is to use soft measures instead of new regulations and thereby convincing employees to change their behaviour. However, if the soft measures turn out to be unsuccessful, the employees who do not conform towards the change are made to do so through hard measures such as enforcing rules. Employees are paid to do their work and most of the times have a superior whose rules they need to comply to. Therefore, the staff cannot always follow their own structures according to their
7.3 Generalisation

Lewin’s model of change is not only a model for organisational Change Management but also for societal change. It is a simple model that allows room for interpretation, which makes it appropriate for many different types of behaviours that are aimed to be changed.
could lead to more frequent construction work, which reduces road capacity (for a short time) and hence, increases traffic congestion. Additionally, even though freight traffic causes congestion, it also reduces the amount of cars on the roads as people who order online do not need to drive to the shops to buy a product. Many more variables need to be taken into account in order to create a consistent CLD that includes all contributors to traffic congestion.

The conceptual solutions extracted from the case study are assumed to be adequate solutions for all suburban municipalities with similar characteristics as Kirchheim as in size, culture, density and occupation just to name a few. However, the analysis was conducted by taking the results specifically for Kirchheim very closely into account. Therefore, some characteristics of the CLD might need to be changed in order to customise it for the specific municipality. Besides, some solutions extracted from the analysis might be outdated or inappropriate for the specific location. However, two main groups of measures have been detected – soft and hard measures. The soft measures work by incentivising the use of car alternatives. This can be for example making PT more convenient, offering low-cost ride sharing services or other innovative solutions that make using alternative MoTs instead of the car more convenient. The hard measures can be introducing rules and regulations on car use by making it more expensive or restrict driving in certain areas or at certain times, e.g. rush hours. Therefore, even though some solutions can be outdated or irrelevant in the future, but what we are looking to achieve with them is the same. No matter what measures a municipality decides to implement, the route cause of traffic congestion needs to be eliminated.

Even though with 261 participants the commuter survey had a high number of respondents, for certain groups the survey is not representative. For instance, only 34 of the participants works and lives in Kirchheim at the same time. This could lead to some conclusions drawn for this group could be faulty. Nevertheless, when looking at the whole number of responses, reliable conclusions can be reached.

When reviewing and analysing the results of the commuter survey, it became clear that some additional questions should have been included. For example, in section 6.2 it was pointed out that the increase in car use at the age above 40 years could be due to a higher number of physical disabilities the older the people are. Yet, this is an assumption. It would have therefore been helpful to have asked a question on physical disabilities.

Lewin’s model of change is basic and ”very rational, goal and plan oriented” (Kritsonis; 2004-2005). Therefore it can be argued that human feelings and experiences are not sufficiently taken into account, which could lead to resistance from the people whose behaviours are attempted to be changed. Moreover, Cummings et al. (2016) point out that is rigid and a linear system is not appropriate in today’s dynamic world. However, it also leaves potential to interpret the stages in different ways, such as not only focussing on organisational change but also societal change as it is done in this thesis. Additionally, exploiting a more extensive model of change would have exceeded the scope of this thesis.
Chapter 8

Conclusions and further research

The thesis finishes off by concluding with the main outcomes of the project, by explaining the implications of the results of this research and by pointing out potential future work that would take the current research further.

8.1 Conclusions

The purpose of this Master’s thesis was to investigate the causes and effects of the increasing strain on transportation infrastructure of suburban municipalities with their dynamics. The development of a CLD was supposed to result in conceptual solutions aimed at improving the traffic situation in the long term.

By using the method SD, a CLD was created which revealed that in order to reduce traffic congestion, road expansion alone is not a viable solution due to rebound effects since it eventually results in increased car use and hence more traffic congestion. Therefore, to solve the problem in the long term, car use needs to be reduced by a significant degree. This can be achieved by implementing various solutions to nudge people towards using alternative MoTs. Various pricing techniques such as free PT are a possible method of approaching this topic. Furthermore, improving PT services and infrastructure by means of digitalisation and centralising various alternative MoTs by implementing a mobility hub are among a number of appropriate ways to effectively reduce the traffic congestion problem studied in this project.

But more than introducing transportation solutions, society needs to be convinced that car use needs to be reduced significantly by changing their travelling habits. In order to do so, a model of change was introduced and applied in the context of achieving a mind shift towards using car alternatives.

This degree project addresses counsels of suburban municipalities, which face the issue of traffic congestion. The work assessed various ways of improving the traffic situation and can be seen as a guide for counsels and city planners to achieve the goal of tackling congestion. Additionally, companies that offer solutions to improve traffic can exploit the potential of their products. The demand for these types of solutions can be expected to rise even more in future, the more serious the traffic situation becomes. Therefore, other companies can utilise the opportunity of this growing market by developing innovative products to satisfy customer needs. Hereby, the customers can be individuals, municipality counsels, city planners and many more. Lastly, individuals considering to start their own business with an innovative product that is also beneficial for society can build upon this knowledge.

The CLD created serves as an appropriate basis towards creating a more extensive and
detailed CLD, which can then be converted into a stock-and-flow model to quantify and simulate possible implications of reducing car use with various measures.

In practice, the result of the analysis and discussion showed that by investing in road capacity expansions, traffic congestion cannot be reduced in the long run. However, other solutions need to be implemented that give commuters and other frequent travellers an alternative to using the car as this is the main contributor towards traffic congestion. Moreover, in order to achieve a reduction in car use, also a habitual change of commuters needs to take place which can be carried out with Change Management. However, not only Change Management needs to be conducted but also the infrastructure and service for car alternatives in municipalities and cities needs to be improved in order to incentivise their use.

It also needs to be considered, depending on which conceptual solutions a suburban municipality decides to implement, whether policies need to be undertaken to enforce this societal change. As mentioned in the discussion, a type of reward should be handed out in order to refreeze the new norm. Therefore, the type of reward should be decided on.

In the field of mobility, many innovative solutions are available and constantly being developed such as different smart city technologies. This topic is very broad and therefore it needs to be decided, which technologies are appropriate and complement each other to make a city more smart.

### 8.2 Further research

Since creating the CLD was conducted qualitatively only to visualise the patterns of behaviour, creating a quantified stock-and-flow model would have exceeded the scope of this thesis. However, it is of interest to expand the CLD and convert it into a stock-and-flow model to simulate the behaviour of the system when implementing several of the recommended solutions. This might even result in observing unexpected patterns of behaviour that could not be seen by simply interpreting the CLD. Moreover, to make the CLD more reliable, it is recommended to conduct further research to add variables that affect the currently considered exogenous ones. Especially the psychological effects should be taken into consideration as well as other vehicles that contribute to traffic congestion.

Moreover, a feasibility study on the conceptual solutions developed in this thesis, such as fare-free PT and mobility hubs, should be conducted to find out if they have the potential to reduce traffic congestion and are cost-effective. Additionally, the recommended solutions considered to be feasible should be implemented in a suburban municipality to measure their impact.

The conceptual solutions provided are just a small number of possible implications. However, many more solutions can be developed through further research.
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Appendix A

Maps of Kirchheim

Figure A.1: The municipality of Kirchheim (Google; 2019)
Figure A.2: Locations of industrial estates in Kirchheim (Google; 2019)
Figure A.3: MVV network (MVV GmbH; 2019)
Appendix B

Commuter survey

In the course of the project two commuter surveys were conducted for the two groups of Kirchheim’s citizens and employees of Kirchheim’s companies. This was necessary because some questions needed to be different for the groups. However, they were treated as one survey in the analysis. To understand if questions are only relevant for either of the groups, it is marked in brackets behind the questions.

Some of the questions are only conditionally relevant if a previous question was answered with a specific criteria. In this case, they are marked at the beginning of the question, e.g. ‘If car’.

Lastly, the questions that were compulsory to be answered are marked by a star (*).

Welcome message

Analysis to improve the commuting experience

Commuting is becoming increasingly exhausting. Whether through traffic jams, too little flexibility or delays – at one time or another, we have all arrived at work irritated or we were unable to enjoy a well-deserved evening after work due to various mobility issues. Furthermore, both local inhabitants and the employees of businesses in Kirchheim have increasingly been struggling with traffic when commuting.

The municipality of Kirchheim has addressed this problem in a number of ways. She is, among other things, a member of the Smart Mobility Initiative endorsed by the Chamber of Industry and Commerce (IHK) Munich, which investigates and tests several solutions to improve the mobility in Kirchheim. IABG mbH in Ottobrunn is part of this initiative and supports me in my Master’s thesis at Uppsala University of conducting a situation analysis in Kirchheim. Based on this survey, I will assess the commuting habits of people travelling to and from Kirchheim. Moreover, this questionnaire assesses your expectations concerning mobility with the aim of improving your commuting experience in the future.

It takes between 5 and 7 minutes to complete the survey and your response will be treated anonymously. You may only participate once, but you can modify your responses at any time before the deadline on 26 April 2019. The questions marked with a star (*) need to be completed.

If you have any questions regarding the survey, please do not hesitate to contact me at: xxx@iabg.de
I would like to thank you in advance for your support. Together, we can effectively address our mobility problem.
Best regards Sophia Cullen

Let’s get started…

**General questions**

1. Do you live in the municipality of Kirchheim?* (only for Kirchheim’s citizens)
   - Yes
   - No

2. Please specify your gender.*
   - Female
   - Male
   - Other

3. How old are you?*
   - Below 20 years
   - 20 to 29 years
   - 30 to 39 years
   - 40 to 49 years
   - 50 to 59 years
   - 60 years or above

4. Please specify the 5-digit postcode of your workplace.* (only for Kirchheim’s citizens)
   - Numerical input

5. Where in Kirchheim is your workplace located?* (only for Kirchheim’s employees)
   - Industrial estate Kirchheim I
   - Industrial estate Kirchheim II Heimstetten
   - Other location in the municipality of Kirchheim

6. Please specify the 5-digit postcode of your place of residence.* (only for Kirchheim’s employees)
   - Numerical input

7. How high is your monthly net income? (optional)
   - Below 1,000 €
   - 1,000 € to 2,000 €
   - 2,000 € to 3,000 €
   - 3,000 € to 4,000 €
   - 4,000 € to 5,000 €
   - above 5,000 €

8. Do you have underage children?
   - Yes
   - No

9. If yes: How old is your youngest child?
   - Infancy
• Nursery age
• Primary school age
• Above primary school age

Questions on commuting habits

1. How many minutes does your commute take from door to door per way?*
   - Numerical input

2. Which modes of transportation do you currently use to reach your workplace? Please also specify any modes of transportation you use for only part of your commute (e.g. taking your car to the train station and then continuing by S-Bahn).*
   - Car (alone)
   - Car (carpooling)
   - Bicycle
   - On foot
   - Public transportation (bus, S-Bahn, tram)
   - Other

3. If carpooling: Are you regularly the driver of the carpooling group?*
   - Yes
   - No

4. If carpooling: How many people are part of the carpooling group?*
   - 2 - 3
   - 4 or more

5. If carpooling: How many days per week do you carpool for your commute? Please also take into account when carpooling for only part of the route (e.g. from home to the train station).*
   - 1 - 2 days
   - 3 - 4 days
   - Daily

6. If carpooling: Why do you carpool for your commute?*
   - Time
   - Comfort
   - Costs
   - Flexibility
   - Safety
   - Sustainability
   - No or insufficient public transportation
   - No own car available
   - Other

7. If carpooling: Do you carpool for the whole route of your commute?*
   - Yes
   - No (e.g. to the train station)
   - Varying

8. If car (alone) or carpooling & driving: Do you use a company car?*
9. If *car (alone)*: How many days per week do you commute by car (no carpooling)? Please also take into account when using your car for only part of the route (e.g. from home to the train station).*
   • 1 - 2 days
   • 3 - 4 days
   • Daily

10. If *car (alone)*: Why do you commute by car?*
    • Time
    • Comfort
    • Costs
    • Flexibility
    • Safety
    • Sustainability
    • No or insufficient public transportation
    • Other

11. If *car (alone)*: Do you use the car for the whole route of your commute?*
    • Yes
    • No (e.g. to the train station)
    • Varying

12. If *bicycle*: How many days per week do you use the bicycle for your commute? Please also take into account when cycling only part of the route (e.g. from home to the train station).*
    • 1 - 2 days
    • 3 - 4 days
    • Daily

13. If *bicycle*: Why do you use the bicycle for your commute?*
    • Time
    • Comfort
    • Costs
    • Flexibility
    • Safety
    • Sustainability
    • Health
    • No or insufficient public transportation
    • No own car available
    • Other

14. If *bicycle*: Do you cycle the whole route of your commute?*
    • Yes
    • No (e.g. to the train station)
    • Varying

15. If *on foot*: How many days per week do you walk to work? Please also take into account when walking only a part of the route (e.g. from train station to office).*
16. If *on foot*: Why do you walk to work (whole or partial route)?*
   - Time
   - Comfort
   - Costs
   - Flexibility
   - Safety
   - Sustainability
   - Health
   - No or insufficient public transportation
   - No own car available
   - Other

17. If *on foot*: Do you walk the whole route of your commute?*
   - Yes
   - No (e.g. to the train station)
   - Varying

18. If *PT*: How many days per week do you use public transportation for your commute?
   Please also take into account when using public transportation for only part of the route (e.g. take the S-Bahn and then walk).*
   - 1 - 2 days
   - 3 - 4 days
   - Daily

19. If *PT*: Why do you use public transportation for your commute?*
   - Time
   - Comfort
   - Costs
   - Flexibility
   - Safety
   - Sustainability
   - No own car available
   - Other

20. If *other*: You previously selected "Other" as chosen mode of transportation for your commute. Please specify the type of mode of transportation.*
   - Text input

21. If *other*: How often per week do you use this mode of transportation for your commute?
   Please also take into account when using this mode of transportation for only part of the route.*
   - 1 - 2 days
   - 3 - 4 days
   - Daily

22. If *other*: Why do you use this mode of transportation for your commute?*
• Time
• Comfort
• Costs
• Flexibility
• Safety
• Sustainability
• No or insufficient public transportation
• No own car available
• Other

23. If other: Do you use this mode of transportation for the whole route of your commute?*
• Yes
• No (e.g. to the train station)
• Varying

Questions on satisfaction
Please share your experience on your commute.

1. You are satisfied with the duration of your commute.*
   • Strongly disagree
   • Disagree
   • Agree
   • Strongly agree
   • No statement

2. You make good use of the time you spend commuting (e.g. to work, read).*
   • Strongly disagree
   • Disagree
   • Agree
   • Strongly agree
   • No statement

3. The financial cost of your chosen mode of transportation is appropriate for its quality.*
   • Strongly disagree
   • Disagree
   • Agree
   • Strongly agree
   • No statement

4. You can choose between different modes of transportation to reach your workplace (e.g. between public transportation and car).*
   • Strongly disagree
   • Disagree
   • Agree
   • Strongly agree
   • No statement

5. You experience your commute as a burden, which has a negative impact on your well-being.*
   • Strongly disagree
6. You are willing to pay more for your commute in order to reduce commuting time (e.g. directly by car instead of changing several times when using public transportation).*

- Strongly disagree
- Disagree
- Agree
- Strongly agree
- No statement

7. You question your commuting habits once in a while.*

- Strongly disagree
- Disagree
- Agree
- Strongly agree
- No statement

8. The use of a low-emission vehicle is important to you.*

- Strongly disagree
- Disagree
- Agree
- Strongly agree
- No statement

9. In order to be flexible, you are willing to pay more for your commute (e.g. drive alone instead of carpooling).*

- Strongly disagree
- Disagree
- Agree
- Strongly agree
- No statement

Future outlook

1. If car: In which case would you be willing to change from using your car to another mode of transportation?

- Text input

2. How do you imagine your ideal commute?

- Text input

End message

You made it!

Thank you for your participation in this survey and your support for my Master’s thesis.

In case you are interested in the results of this survey or you have further questions, please contact me by mail at: xxx@iabg.de