Technical University of Munich

The Impact of Autonomous Parking on Land-Use and Transport

With a Case Study of Munich

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Abstract

The aim of this master's thesis was to investigate how on-street parking spaces in cities can be reclaimed for alternative use through autonomous driving. It had become apparent that there was a research gap for this topic in the literature. The city of Munich served as a case study. First of all, the evaluation of aerial photographs was used to investigate how large the area potential is, and which alternative areas are suitable for shifting parking there. The potential areas found were divided into different types, depending on the land use, and assessed for their potential. The assessment was based on various criteria that were either taken from the literature or obtained through expert interviews. For this purpose, a wide range of experts from municipal administrations and from different business sectors were recruited. Furthermore, it was investigated how the identified areas could be parked in the most efficient way. It was shown that conventional parking facilities can be used less efficiently than automated parking systems. Consequently, the latter were used for the dimensioning of the alternative parking areas. A methodology was developed to calculate how many vehicles an identified space can accommodate. It was shown that all on-street parking vehicles in Munich can be accommodated in alternative spaces. MATSim modelling was used to examine how traffic changes when additional parking trips occur between the newly allocated parking spaces and the pick-up / drop-off location. A methodology was developed to add these additional parking trips to an existing dataset and to simulate this changed traffic pattern. Four different scenarios could be designed with different numbers of garages, as well as one scenario with a parking-free Munich city centre area. It was found that the average delay per trip increases significantly in the four scenarios with collective garages compared to the baseline scenario. This is due to the effect of the mass backlog in the parking infrastructure at the access point of the collective garage to the road infrastructure. Nevertheless, it has also been shown that a parking-free centre has a slightly positive effect on the total delay time of Munich traffic. The depth of evaluation can still be extended here to obtain even more reliable and specific data. In particular, the bottle necks at the collective garages have a major effect on the results of the simulation. Overall, the work has shown that there is great potential to return development space to city centres through alternative parking. This is possible on the one hand with the concept of shared parking and on the other hand by making other already sealed areas available for parking. At the same time, the work has also shown how important it is to manage autonomous or future traffic in general at an early stage and to pay more attention to parking in general.

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List of Abbreviations

DB	Deutsche Bahn
DO	Drop-Off
G	Garage (in the context of *MunichG*)
I	Intermediate Garage (in the context of *MunichI*)
MiD	Mobilität in Deutschland
P&R	Park and Ride
PU	Pick-Up
S	Short-term Parking (in the context of *MunichS*)

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1. Introduction

1.1. Motivation

Despite the expansion of public transport, ever new mobility offers, an increased awareness of the problems of climate change, the fact that individual transport is not noticeably decreasing and even is increasing in many places is a matter of great concern to me. The fact that the number of vehicles in Germany continues to rise, although the total population remains more or less the same, also gives me pause for thought. The effects of individual mass mobility on the consumption of resources through the production of vehicles, but also the effects on the climate and air have been widely researched. E-mobility and the networking of vehicles, as well as driverless driving, will change motorised individual transport and also public transport. It must be examined how these new possibilities can lead to a real change in mobility.

As an environmental engineer specialising in sustainable settlement and transport planning, I have been involved for years not only working on solutions for the transport sector, but also with developments in settlement development. Increasing urbanisation and migration in certain regions are leading to changes in land use. The creation of new living space but also of areas for cars leads on one hand to the expansion of settlement areas and on the other hand to further densification through new building structures. In both cases, this has an impact on nature, climate and quality of life. Where land is sealed and natural areas have to give way, the microclimate also changes and with it the challenges for municipalities to provide compensation. With increasing density, there is also a lack of space to establish new infrastructures. For several semesters now, I have been asking myself which challenges this poses for the design of the city of the future.

The idea of decoupling building projects from parking space requirements and making streets car-free again is very appealing to me and motivates me to investigate what contribution traffic automation could make to this. At the same time, simply replacing today's vehicles with electric, autonomous vehicles - for reasons of high resource input alone - cannot be the main concept of the mobility turnaround. The establishment of further mobility services also does not seem to lead to a significant mobility turnaround. We have to think about other instruments than the ones used so far in order to reduce motorised individual transport. I would like to address the fact that the mobility turnaround is also closely linked to the distribution of land. Above all, however, I would like to show that a great deal of land is already being used for single purposes, and that it can be put to double or multiple uses in a way that makes sense from both an urban planning and an ecological point of view. Autonomous vehicles can, if they can, facilitate the use of these sites. Working out this connection is what motivates me to write this paper.

I know Munich well from my student days. The state capital is known for its high quality of life also because of its many parks and green spaces. The city has particularly beautiful streets and neighbourhoods that are also popular with foreigners. Unfortunately, the full splendour can often only be glimpsed at because the street side spaces are mostly fully parked.

1.2. Focus and Scope

The aim of this thesis is to investigate the influence and possibilities of autonomous driving and especially parking on land use and traffic patterns. This investigation is based on the assumption that the spatial proximity between the location of the vehicle user's activity and the parking location of the vehicle will become less relevant in the future and that vehicles can be digitally networked and controlled without a driver. They can then be sent to park and also be called back again. This function makes it possible to reuse valuable urban spaces that are currently allocated to stationary traffic. At the same time, future parking areas can be realised with a smaller footprint per vehicle.

The aim of this study is to investigate how a more efficient parking area design can look like and which current or alternative locations are suitable for this. It will also be investigated how realistic it is to implement this project on these sites and which ecological factors play a role in it. Furthermore, it will be investigated how the traffic situation changes if additional parking trips for calling the vehicles before the start of a trip, as well as sending the vehicles to their parking location, influence the existing traffic situation. For this purpose, several scenarios with different numbers of collective parking garages are to be designed, with the help of which the change in traffic flow at certain locations and around the locations of the collective parking garages as well as in the entire study region is to be made visible and quantifiable. The aim is also to give a brief overview of which possible conversions are conceivable. This is also intended to provide a more precise assessment of which areas can be assigned which value. The study area is the state capital of Munich.

1.3. Overview

First of all, a literature review follows in which literature concerning both flowing traffic with autonomous vehicles and stationary traffic and its relationship to land use was examined. Parking system solutions and the interaction between autonomous traffic and the environmental network also play a role in the selection of literature.

This is followed by the chapter on “methodology”, in which the methods are named and, for the most part, the approach is described. The description of the procedure for the elaboration of codes for the simulation is spread over these chapters as well as over the chapter subchapter Simulation in the main part Munich.

A problem description and a predominantly technical description of parking infrastructure and the classification of transport infrastructure of municipal areas is given in the chapter “Study Area”.

In the “Case Study Munich” chapter an overview is first given of common parameters that help to assess the current situation of stationary and moving traffic in Munich. Then the current parking infrastructure is analysed. This is followed by an analysis of alternative parking areas and the elaboration of the potentials of different area types for a new parking infrastructure. The simulation subchapter describes how the modelling of the flowing traffic was carried out, taking into account different scenarios with different parking infrastructures. Subsequently, the results are presented.

In the next chapter “Future concepts” a selection of conversion options is presented. This chapter includes considerations on how an alternative parking infrastructure can be implemented in Munich today using the findings from the previous chapters and other case examples.

This is followed by the chapter "Discussion" in which the results obtained so far are discussed together and answers are given as to what extent the results were expected and support the research hypothesis. The final chapter offers a reflection on the work, shows limitations and also contains a personal assessment.

2. Literature Review

2.1. Autonomous Driving

The initial euphoria surrounding the topic of driverless driving has waned somewhat over time. Technical, but above all ethical and legal questions have postponed the first use of driverless vehicles in regular traffic on publicly accessible roads to an unspecified date in the future. At the same time, the use of semi-autonomous technology is becoming increasingly popular.

Many publications have already been published on autonomous driving. There are studies that examine the potential of autonomous driving and its' opportunities especially in regard to the technical aspect of efficiency, but also literature that identifies risks involved in the interaction of between autonomous driving and with other means of transport and road users.

There is undisputed potential to improve traffic flow, increase road safety, save personnel costs, and make carpooling easier. By increasing the efficiency of the means of transport, the energy demand of transport can be reduced (with the same number of vehicles), as well as environmentally and climate-damaging gases. At the same time, transport routes can be used more efficiently. Friedrich (2015) found that in the optimal case, through increased efficiency, increases in capacity of 40 percent in urban traffic and 80 percent on the motorway are possible. His findings are based on the assumption that all road traffic is fully automated (autonomous driving) and that no hand-guided participants can impede smooth traffic. In another study, Friedrich and Hartl (2017) investigated the effects of autonomous vehicles on urban traffic. This study showed that the number of vehicles in a vehicle fleet as well as the traffic performance can be reduced if around 50 percent of the changes of location use ridesharing systems.

Kickhöfer (2017) assumed that autonomous driving will not bring about a shift to shared mobility, but that the comfort gains will perpetuate the trend towards owning a vehicle. Knie et al. (2019) also predicted an increase in the stock of private vehicles and saw increasing competition for space with other transport modes and carriers as a consequence. They emphasised that public transport and the rail mode (passenger and freight transport) could lose significant shares and that this would have an overall negative ecological effect. Fraedrich et al. (2017) also expected an ecological added value only if electrification is associated with automation. Friedrich and Hartl (2017) expected differences in the impact of autonomous vehicles on urban and rural transport. They argued that large parts of so-called high-performance public transport with urban correlations continue to have time advantages over individual transport, while at the same time, shared autonomous vehicles in cities have significantly higher occupancy rates and can therefore be economically attractive. They also came to the conclusion that without accompanying measures, public transport will regress and at the same time autonomous driving will lead to an increase in car traffic and a deterioration in traffic flow in urban areas. Friedrich and Hartl (2017) also saw growth because autonomous driving also makes it easier for people without a driving licence to access individual mobility and the new technology does not necessarily increase the costs of individual driving.

The fact that both the potential and the early introduction of autonomous driving could be overestimated was emphasised by (Litman, 2021). He referred on the one hand to the complexity of the technology, which makes the purchase of these vehicles unattractive at the beginning of development, and on the other hand to the drivers of development from the technology sector, who tend to ignore risks and exaggerate potentials.

2.2. Parking and Land-Use

In a transition phase, autonomous vehicles will have to meet and react to hand-guided vehicles. Coordination issues also arise for the parking infrastructure. Wu et al. (2021) investigated how autonomous vehicles and human-operated vehicles can be organised together in a parking infrastructure. The authors see potential for conflict if the human-operated vehicles cannot communicate with a central control centre. The authors identified a pattern that can be used to describe the parking behaviour of humans in order to allocate parking spaces to autonomous vehicles.

Bartulis and Mockus (2009) investigated the problem of increasing parking demand in densely built, growing cities using Vilnius as a case study. They found that the combination of smaller automated parking systems and multi-storey automated car parks, instead of open, single-storey car parks or traditional car parks, can be an asset for city centres. Their research showed that automated parking systems can save time and fuel for drivers. They also pointed to the associated environmental effects, reduced accident risk and net space gains.

Municipalities are countering the increasing demand for parking by creating parking space requirements. Manville and Shoup (2010) described the problem when residential parking requirements prevent the creation of living spaces. They showed that new parking requirements made it impossible to reoccupy a long vacant building with several residential units. They found out that the requirements are often formulated very rigidly and do not take into account local conditions such as structure of the settlement, type of buildings good public transport connections.

Sustainable infrastructure requires that future needs are also taken into account. Malysheva and Generalova (2020) note that the life cycles of urban infrastructure are becoming shorter and shorter, as only currently detectable problems and solutions to problems are taken into account. They continued that parking areas planned today must either meet future needs or be convertible. They also claim that the potential to convert underground car parks is very low, whereas the parking infrastructure above ground is much easier to convert or deconstruct.

Marsden (2014) examined the impact of policy interventions on the parking market. He found that current policies can lead to a net welfare loss and artificially inflate supply by setting minimum standards, while the private sector would find other ways. He also stated that parking management must be seen much more as an instrument of the transport turnaround in the future and must contribute to achieving the goals of sustainability.

Large commuter flows also bring high parking pressure for the municipality into which they commute. Hagen and Reining (2019) found that congestion charging can be an effective tool to discourage commuters from parking in cities. At the same time, they point out that depending on the design of the toll, commuting can also be shifted to the edge of the toll zone or outside the toll period. Overall, the authors concluded that the introduction of the toll would have a positive effect on traffic, life in the city and the sustainability of land development.

Chai et al. (2020) used a simulation model in San Francisco to investigate the effects of increasing demand for drop-off and pick-up transport by autonomous vehicles on traffic flow, kilometres travelled and CO2 emissions in inner cities compared to current behaviour. The result of their study was that although travel flow improved due to avoided parking search trips and parking spaces were used more effectively, this was offset by increased vehicle movements and an increase in empty passenger traffic. In addition, the authors found that increasing concentration of off-street parking in fewer locations exacerbated congestion.

Estepa et al. (2017) investigated double parking for autonomous vehicles as an approach to temporarily increase parking capacity in locations of high parking pressure. This involves vehicles being blocked by other vehicles and moving autonomously when gaps need to be created for other vehicles parking in or out. They found that double-parking can increase parking capacity in a given area by over 50%, while making the cluttered streets confusing for other road users.

Weldu (2018) investigated the impact of autonomous vehicles on land use and mobility in downtown Stevanger. The focus of this work was the impact on parking areas and transport infrastructure. Weldu identified great potential for the transformation of the city by reorganising the parking areas that serve the city.

(Yekollu, 2020) has also investigated the fact that the use of autonomous vehicles can make parking areas in residential areas superfluous. Yekollu studied properties in Ypsilanti (US) and found that the areas allocated to parking in a single-house development are often larger than the floor area allocated to housing. Yekollu found that autonomous parking in collective parking areas and collective garages can create a very efficient parking infrastructure in loosely but especially in densely built-up areas, while at the same time allowing previous parking spaces to be used in other ways.

In summary, the literature research has shown that autonomous driving and parking have great potential to use parking spaces more efficiently and existing spaces that have then become superfluous can be put to another use. At the same time, additional traffic is generated by empty runs. Due to comfort gains (Kickhöfer, 2017) also compared to public transport (Friedrich and Hartl, 2017), road traffic may increase further. As Manville and Shoup (2010) and Marsden (2014) showed, rigid minimum parking requirements by municipalities can lead to inefficient use of both housing and parking space, and smart parking management can already be used in conjunction with other modes of transport to achieve a modal shift. Tolls and congestion charging can have positive effects in order to further control and direct traffic and thus also parking volumes and parking patterns in a sustainable manner (Hagen and Reining, 2019). In addition, Chai et al. found that the increasing concentration of off-street parking in fewer locations exacerbated congestion.

3. Methodology

The topic of this thesis was developed by the author himself in the run-up to writing this paper. The majority of the methodology was also part of this idea. Only the method of quantitatively determining the change in traffic behaviour by means of a simulation was developed during the coordination of the development of this topic with the supervisor of the thesis.

Hypothesis:

Double and multiple use in temporal staggering or on several spatial levels of already sealed surfaces can completely remove stationary traffic from the street side spaces of an inner city.

The methodology differs depending on the chapter of the thesis. The main results section has been divided mainly into three chapters that build on each other. The chapter structure is therefore also maintained for the description of the methodology.

3.1. Literature Review

In order to be able to narrow down the topic and to determine whether other authors have already examined this topic, a literature search was carried out. Since the topic of this thesis is based on a technology that has not yet been fully developed and there is hardly any practical experience of autonomous driving within urban structures, the area of application was divided into different individual areas, each of which was searched for individually in the literature.

Inevitably linked in the consideration of individual motorised mobility are driving and parking. One area for the literature research was therefore autonomous driving. Here, the state of the art was examined on the basis of the literature, potentials and risks were investigated and the question of interactions between driverless vehicles, driver-guided vehicles and other traffic participants were examined. The focus was on estimating the future area required for moving and stationary motorised individual traffic with passenger cars. Closely connected to the planning of the spaces was the question of how the modal share will be shaped in the future and what role shared mobility can take. In this context, it is not irrelevant for the assessment of traffic infra-structure and ecological consequences whether autonomous driving leads to more traffic and can displace the environmental alliance. Relevant for the research was therefore also the fundamental question of whether autonomous driving will be able to establish itself at all in a foreseeable future and what influence political and social flanking measures can have.

For the second part of the literature research, the findings of research on implemented parking concepts and parking system solutions in cities already have been brought to light. The focus was on the topic of autonomous driving in connection with parking processes, as well as on space-efficient parking concepts in general. It was also important which parking space control instruments municipalities have and how they affect land use and traffic.

3.2. Study Area

The descriptions and distinctions of parking types, as well as a short introduction to the current state of the art of parking systems and the legal classification of parking in Germany were collected in a separate chapter before the main part. For this purpose, technical literature, newspaper articles and the technical descriptions of parking system manufacturers were studied. The classification was made both qualitatively and quantitatively on the basis of researched numerical values, as well as on the basis of an expert interview. At this point, the numerical values also offered the possibility of showing the significance of designated parking areas in terms of area. In addition, a problem description of this research area was written based on literature.

3.3. Case Study: Parking and Traffic in Munich

In the chapter “Case Study: Parking and Traffic in Munich”, on the one hand, the current spatial distribution of parking areas in the state capital of Munich was examined and potential future parking areas were researched. On the other hand, the effects of a spatial change of the parking areas on the flowing traffic, especially by agglomeration of parking possibilities, were investigated and presented. The following work packages were defined to achieve results, which are presented in this chapter:

- Determination of parameters
- Carrying out interviews with experts
- Evaluation of aerial photographs and maps

- Calculation of alternative parking areas and parking systems
- Simulation: Adjusting and expanding populations based on different scenarios
- Analysis of simulated traffic in Munich
- Researching concepts for an alternative parking infrastructure

For this purpose, parameters of the flowing and stationary traffic in Munich were first researched and processed. Expert interviews with specialists from various fields were decisive for the investigation of stationary traffic. As a qualitative method, these expert interviews formed the basis for systematic investigations of different potential parking space types and subsequently for the determination of criteria for the input data of the simulation. A total of 32 experts were approached, of which an interview could be conducted with 13 experts. The expert interviews were requested by telephone or e-mail and were scheduled to last between 30 and 90 minutes and (also due to the pandemic situation) were conducted exclusively by audio/video telephony, as well as one by e-mail. Follow-up questions were also sent by e-mail and in two cases a new telephone call was made.

Various experts from the retail trade, the real estate sector, car park operators and local authorities were asked to assess whether and how commercial space could be built over. For the selection of the experts, further criteria were applied such as:

- Does or could the company already have experience with creative parking system solutions or the dual use of space?
- Does the company have a connection to Munich or are the experiences transferable to Munich and to the study of the present work?

The focus was on large retail chains that had already gained experience in other large cities such as Berlin in the implementation of space-saving concepts and the functional misuse of buildings. The expert interview with a specialist from the real estate industry served to assess whether the idea of operating a park on someone else's property is at all legally and financially attractive and feasible.

The expert interviews with experts from the City of Munich were distributed among the individual departments that were responsible for the respective questions. The questions concerned both the qualitative assessment of current and future traffic development and data material that quantitatively describes the current parking situation. In addition, questions were asked about concepts and instruments with which the city should organise stationary traffic and implement the mobility turnaround as a whole. The considerations underlying the idea of this work, following the investigation of alternative and disruptive parking space redesign, were already included in this.

The interviews yielded numerous clues that were followed up on, reviewed and, for the most part, incorporated into the drafting. Overall, the quality of the interviews was good and helpful. The information and assessments were often of a general nature or related to current planning. In many cases, autonomous driving and parking were not yet a topic for the experts. Experts from these research areas could not be recruited.

In order to analyse transport infrastructure, settlement structure, land types and use and ownership relationships, satellite images and map material were first evaluated via the services Bayern-Atlas and OpenStreetMaps. The map service Bayern-Atlas also offered the function of a quantitative determination of length and area. With the help of QGIS, the geodata obtained could be organised and later combined with the input and output data of the simulation.

Quantitative surveys such as the dimensioning of alternative parking areas, but also the calculation of possible vehicle capacities and other characteristics of alternative car parks were processed in spreadsheet programs.

3.4. Model Creation and Simulation

The simulation is a quantitative method that can be used to model the flowing traffic of the Munich region. The method was chosen because the simulation programme *MATSim* was already used at the research group *Modeling Spatial Mobility*, where this work was supervised. The input data (journey plans of the total population as xml-file, network xml-file, implementation code as java-file, shapefiles of the counties and city districts) were provided by the research group. The input data of the traffic model is based on MITO (Microscopic Transport Orchestrator) a model that generates the travel demand of the synthetic population (cf. Moeckel et al., 2017). In the context of limiting the study area to the capital city of Munich, the input data of the simulation were adjusted (see subchapter “Modelling”).

In order to be able to work with *MATSim*, basic knowledge of Java and object-oriented programming had to be acquired. In addition to technical literature, the *MATSim user guide* and lecture material on *object-oriented modelling* and *Applied Transport Modelling with MATSim* were studied. For the creation of new classes, to rewrite the existing plans, to simulate and evaluate the model, online portals were searched to find solutions and to understand and work with the input data.

The data and assessments obtained up to now were used to create further input data sets and codes for the simulation. First, the structures of the data sets were analysed. Since one of the main goals of this work was to find out what impact additional parking trips of empty autonomous vehicles have in a city like Munich, a way had to be found to classify these trips realistically in terms of time or to assign them to the existing plans at a suitable point.

The addition of the garages and parking drives was done with classes that were written especially for this purpose. An idea of the basic structure of the description and processing of the population (also called plans) could be gained from a sample code that the research group had already provided. The implementation of their own ideas was very time-consuming and involved many thought models. Therefore, the implementation will be seen as the result of the research of this thesis and will be elaborated in subchapter Modelling. *MATSim* in the version of 0.9.0 was used and the integrated development environment IntelliJ IDEA was used. Furthermore, VIA was used for the evaluations.

3.5. Future Concepts

The chapter "Future Concepts" continues the considerations and findings from the previous chapters. Information from the literature research was incorporated, results from the expert interviews and additional case studies in the literature were sought. This chapter was deliberately set apart from the previous ones in order to contrast future-oriented concepts on the one hand and alternative concepts to the model developed in this thesis on the other. It also includes some of the results from the expert interviews, which can be seen as alternative concepts to the idea of this thesis, as well as taking a different approach. The subchapter "Conversion of Transport Infrastructure" was also deliberately placed at the end of the paper in order to be able to present the structure of the idea of this paper in the structure of the paper itself and to guide the reader along this idea. With the help of a case study, the research hypothesis that the vacated spaces can be put to another use was also tested for its validity.

4. Study Area

4.1. Problem Description

The transport sector is one of the most important sectors in the transformation towards an emission-neutral future. Compared to other sectors, transport did not reduce its emissions between 1990 and 2019, but increased them by 33 percent across Europe (European Environment Agency, n.d.; own calculations). Road transport accounts for the largest share of this, at around 71 percent (European Environment Agency, n.d.). This is astonishing for passenger transport alone, as the range of alternatives has been strengthened in many places during the same period. Public transport and the bicycle infrastructure have been expanded and car-sharing complements the environmental network. Despite these offensives, the number of vehicle registrations in Germany, Europe and the world continues to rise. In the industrialised countries, the number of cars almost doubled between 1990 and 2020 from around 361.7 million to around 651 million, while new consumer countries (including China, India, Brazil) have shown the greatest growth, increasing their vehicle stock almost eightfold from around 57.8 million to around 456.7 million (German Federal Environmental Agency, 2020; own calculations).

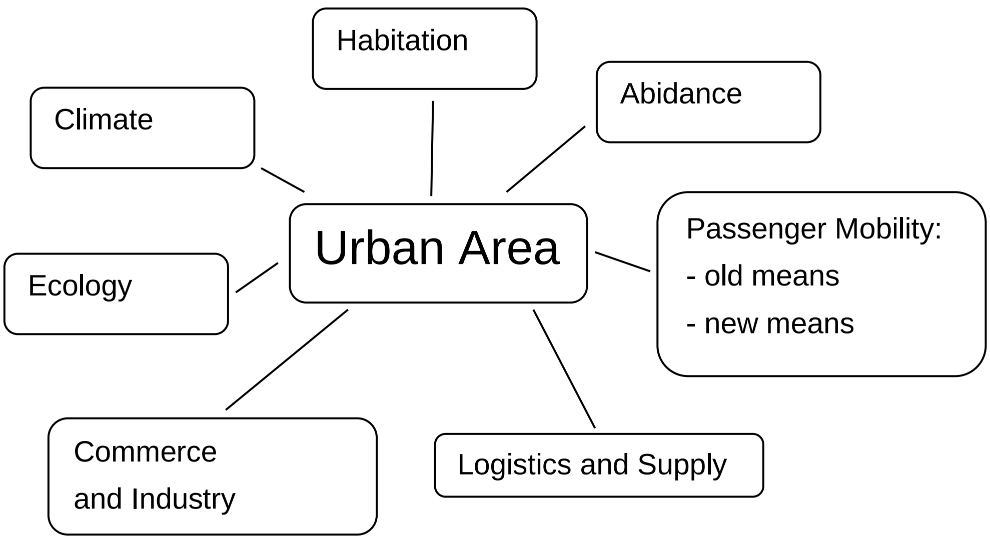
At the same time as the number of vehicles increases, so does the need for parking space. As a rule, each vehicle requires both a parking space at home and additional public and private parking spaces. As a result, the demand for space increases with the number of registered vehicles. Traffic is a change of place and not the standing still of vehicles. Notz (2017) describes the state of a parked vehicle as "death time", which in the sense of a "production factor" does not produce any output during this time (Notz, 2017, p. 18). Vehicles tend to be moved much less frequently in cities than in more rural areas. In the core cities, 10 percent of cars are even only moved on 1-3 days per month and occupy urban space the rest of the time (Notz, 2017, p. 18).

A report by the European Court of Auditors (2018) stresses that risks from land degradation are increasing across Europe, but policies are inconsistent, new guidelines are needed to conserve soil and achieve land degradation neutrality (European Court of Auditors, 2018). The global trend of urbanisation intensifies land competition in urban areas. On the one hand, the aim is to save space by means of redensification, but on the other hand, with each additional inhabitant, the demand for parking spaces per neighbourhood also grows. The air quality of many cities is suffering as a result of increasing traffic, increasing building density and advancing climate change, but the heat island effect also leads to health problems. Parked vehicles have a negative impact on the safety of other road users, in particular by obstructing their view (Sachverständigenrat für Umweltfragen, 2016, p. 358).

Traffic and land use are mutually dependent. A new technology - automated driving - promises greater efficiency while driving, and through networking also precise coordination with other vehicles or parking facilities. Vehicles can be parked in a different location from where their users are. However, the geographical distance between where the user is staying and where the vehicle is parked generates empty runs that induce additional traffic. But even today, about 30 percent of traffic in city centres is caused by parking search traffic, for which the driver needs about 8 minutes, travels about 8.5 km and causes additional congestion (Wittowsky, 2019).

The problem is particularly acute in Munich. The metropolitan region is characterised by an influx of people, rising property prices and growing traffic. This is also growing because the number of vehicles per person is increasing (Landeshauptstadt München, 2020a). But the offer of new means of mobility such as scooter-, bike- and car-sharing is also growing and with it the need to generate space for their use and parking. Overall, different requirements for urban areas were defined, which are presented in the following overview and which are in direct spatial competition.

Requirements for urban areas:



4.2. Parking: A Technical Description and Documentation

4.2.1. Stationary Traffic

Parking areas or areas for the accommodation of stationary traffic have taken up an important part in the structure of settlements. Particularly in urban areas, where the density of development is high and the spaces are contested, regulations and concepts are needed to meet the different demands on spaces and to organise the parking areas as efficiently as possible.

For Germany, experts assume that there are approximately 2.5 to 3 parking spaces available or planned for each private passenger car. The parking area per parking space in Germany is usually about 12.5 square metres (Bundesstiftung Baukultur, 2019, p. 78). Assuming almost 48 million vehicles (in 2020) three parking spaces per car would result in a total parking area of 1800 km², which is more than twice the area of Berlin (Statista, 2021; own calculations). Mohnheim (2018) even assumes that 160 million parking spaces are distributed across the entire Federal Republic. This corresponds to an area of 2000 km² that is reserved for parking only.

According to *Mobilität in Deutschland 2017*, cars park in Germany 97 percent of the time. Furthermore, the study states that 75 percent of all cars in Germany park on private property and 5 percent in underground car parks / parking garages, 19 percent of vehicles are parked on public roads. It is also learned that at just under 50 percent, the number of vehicles parked in public street space is highest in metropolitan areas. Already in a metropolis / regiopolis the share decreases significantly and parking on private property dominates. The smaller or more rural the area becomes, the less important is parking in public street space (2018, p.76).

According to Notz (in Ringwald et al., 2018, p.14), the construction of a single parking space costs 1,500 euros, while Becker (in Ringwald et al., 2018, p.14) assumes 5,000 euros. According to Notz (2017), a parking space costs 60 euros per year to maintain, while Becker (2016) assumes annual operating costs of 300 to 500 euros (in Ringwald et al., 2018, p.14). Türck (2020) assumes project costs of 300-350 euros per square metre for the construction of public spaces, including planning, approval and 10 percent uncertainty. He points out that the costs of the surrounding infrastructure must also be taken into account, e.g. tramlines, greening, shading.

4.2.2. On-Street and Off-Street Parking

On-street parking refers to parking in spaces that are either on the road itself or in the roadside space immediately adjacent to the carriageway of the road. Like the roads themselves, these spaces are usually owned and managed by the public sector. Therefore, on-street parking is almost always associated with public parking.

There are usually three different types of on-street parking:

- Longitudinal parking
- Diagonal parking
- Transverse parking

In Germany, parking areas do not have to be designated separately; on the contrary, areas are defined in which parking is restricted. The control of on-street parking areas is the responsibility of the traffic police. In many cities and especially in districts with high parking pressure, on-street parking areas are organised with a parking management system in order to provide residents with parking facilities close to their homes and to motivate commuters to use public transport (Stopka, 2019).

Off-street parking is the term used to describe off-street parking areas. Off-street parking areas can be public and also private. These include:

- Commercial: employee parking spaces, customer parking spaces
- multi-storey car parks
- Residents' garages
- Parking areas on your own property

In many places in Germany, a minimum number of parking spaces on one's own property is regulated by parking space statutes.

4.2.3. Automatic Parking Systems

In this thesis, an automatic parking system is defined as a parking system in which vehicles are handed over at a transfer point of a collective garage and are brought from there to their destination point in the collective garage by an automatic system. This can be done either with a "stacker crane" that grips the vehicles with robotic arms or with a pallet system in which the vehicle always remains on a pallet that is then moved within the collective garage by skilful shifting (Jünemann et al., 2012).

According to Rosendahl (2021), experience with automatic parking systems has already existed for several decades. He states that both Birmingham of the 1930s and Boston of the 1960s knew (semi-) automated parking garages. The most widespread use of these systems to date is in Japan. Especially in Tokyo, there are a lot of automated parking solutions in a very small space, says Rosendahl. He notes that this market is closed to foreign manufacturers. He further explains that automatic parking systems are also available in Germany, but many car park operators shy away from using this technology more often and prefer classic car parks instead. He says that this is also due to the initially higher initial investment costs but increasingly, large technology companies may be interested in implementing such systems.

According to Jünemann et al. (2012), Rosendahl and the manufacturer's information, there are some outstanding advantages:

- Minimum footprint due to
    - No access and connecting roads necessary to bridge floors, but only a transfer station or shaft between the parked vehicles.
    - Omission of staircase
- Low ceiling height
- User guidance becomes superfluous
- Reduced risk of accidents due to standardised parking procedures
- Time saving for the customer due to the elimination of parking trips (cf. Mockus & Bartulis, 2009)

The major disadvantages are:

- Dependence on technology: what in case of failure?
- Dependence on the car park: what in case of renovation?

As far as the disadvantages are concerned, the question remains as to what happens to the vehicles parked in a large car park in the event of a breakdown. Redundancies have to be planned here.

One of the largest is in Aarhus with almost 1000 parking spaces (Lödige Industries, n.d.-a). But this technology is also used in Munich at Donnersberger Straße.

4.2.4. Semi-Autonomous Parking Systems

The automated parking systems on the driver's level that have been widespread up to now are limited to parking in a parking space when the vehicle is already in the immediate vicinity of the parking slot. The driver can already leave the vehicle and instruct the vehicle to drive into the parking slot independently (Association of the German Automotive Industry, 2017). This technology is already available with “level 3” and is also known as parking assistance. This technology can also help to park a vehicle in small, narrow parking spaces or parking spaces with other imponderables. This can also optimise the utilisation of the parking infrastructure.

Another already widespread and applied technology is the detection of the occupancy of a multi-storey car park, a parking space or even individual parking slots with the help of sensors (Human, 2019). Very common in car parks is the detection of occupancy during the entry and exit of vehicles by means of cameras or sensors. The sensor system detects entering and exiting vehicles and can thus calculate and indicate how high the occupancy is.

4.2.5. Valet Parking

Another technology that relies on semi-autonomous driving inside car parks is “valet parking”. Bosch has developed a driverless parking service that allows the vehicle to start from a handover point, find a free parking slot and park there independently. Bosch equips vehicles and parking garages with the necessary sensors and cameras that interact with each other (Fischer, 2020b). The technology had its world premiere at the Mercedes-Benz Museum in Stuttgart in 2019. The technology has furthermore already been installed in the first series-produced vehicle and is also soon to be used in the multi-storey car park at Stuttgart Airport, which is currently being converted for this purpose (Fischer, 2020a).

The advantages for this technology are initially mainly convenience gains for parking customers. Customers save time and annoyance during the parking process. As Bosch explains, the customer places his vehicle in a specially provided slot in the entrance area of the car park, gets out and moves away from the vehicle. The parking process can be started and monitored via a smartphone application. The customer can leave the parking garage after starting the parking process. During parking, the vehicle detects static and dynamic obstacles such as other buildings, other vehicles and people and reacts defensively to them (Fischer, 2020b).

By arranging the parking slot with a shorter distance to the next parked vehicle, the parking slot can be made narrower and thus, according to Bosch (Fischer, 2020a) 20 percent more vehicles can be parked in the same space.

5. Case Study: Parking and Traffic in Munich

5.1. Characteristic Parameters

According to a study, the state capital is the most densely populated city in Germany in 2019 (INRIX, 2020). It goes on to say that motorists in Munich spent an average of 87 hours in traffic jams, resulting in congestion costs of over 400 million euros for the city. There are many reasons for the tense traffic situation, but not only commuters contribute to the use of the transport infrastructure by commuting in and out, there is also increasing pressure on space in Munich due to population growth. Schütte (2021) expects a growth of more than 200,000 people in the coming decades and accompanying major bottlenecks in the transport infrastructure, especially during rush hours.

In 2019, the state capital with its approximately 1,560,000 inhabitants has a motorisation rate of 51 percent with just under 800,000 registered vehicles (*Verkehr in München*, 2020). This means that Munich has a significantly higher degree of motorisation than other cities in Germany, such as Berlin with around 34 percent (DeStatis, 2020). Compared to the last Mobility in Germany (MiD) survey in 2008, the modal share of private motorised transport decreased from 27 to 24 percent in the 2017 survey (Robert & Belz, 2018). The study further suggests that every Munich resident travels an average of 12.5 km per day, with car self-drivers and car passengers travelling the furthest distances, 18.9 km and 25.8 km respectively.

It is interesting in this context that there is a correlation between the place of residence within Munich and car use. For example, the same study shows that residents outside the "Mittlere Ring" use their cars twice as often as residents within the "Mittlere Ring", at around 24 percent. The frequency of use is particularly high in the north-western districts of the city and in the easternmost in Trudering Riem.

> Explanation: The “Mittlere Ring” is a 28 km long continuous ring road that lies entirely within the urban area of Munich and is often used to delimit an inner-city area and therefore also for urban planning.

The state capital Munich is characterised by commuter movements. Among all German cities, Munich is the city with the most inward commuters (Bundesstiftung Baukultur, 2019, p. 76). A good job offer of just under 900,000 people in employment subject to social insurance contributions (Landeshauptstadt München, 2020b) attracts commuters from other districts. The Commuter Atlas (*Pendleratlas - Statistik der Bundesagentur für Arbeit*, 2020) examines ten districts in the immediate vicinity (approx. 150 km) and shows a balance of outward and inward commuters of +229,914. Employees commute to the state capital primarily from the surrounding district of Munich (see also following figure 1).

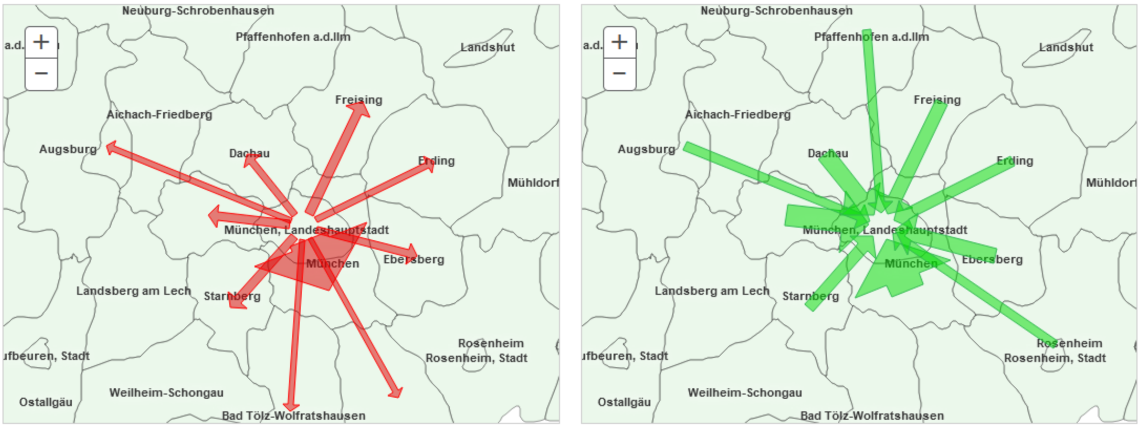


Figure 1 Commuters of Munich, Source: (*Pendleratlas - Statistik der Bundesagentur für Arbeit*, 2020)

Relevant for determining the parking demand in the state capital Munich is in particular the number of commuters who come by car. They park in the available public and private parking spaces and additional spaces will be created for them to alleviate the parking pressure. The state capital, like other cities, is increasingly relying on parking space management (see chapter on parking space management). The aim is also to motivate commuters to switch to other means of transport by reducing parking space in certain areas (Klug, 2020; Landeshauptstadt München, n. d.).

5.2. Parking Infrastructure

5.2.1. Analysis of the Status Quo

There are no large vacant areas in Munich that are owned by the city or that can be developed by the city. Two examples show how the city wants to make more land usable. One is the designation of new planning areas / building areas such as in the north of Munich. Here, residential areas are to be built on large agricultural fields (Stadtrat München, 2020). Another possibility is commercial land, where businesses either move to the outskirts of the city or manage with less land. The largest area currently undergoing rezoning is the abattoir and possibly the wholesale market hall (Landeshauptstadt München, 2019).

When examining parking areas in Munich by analysing aerial photographs (Bayern-Atlas), a typical pattern can be identified: larger open-air parking areas are found on the outskirts of the city, while multi-storey and underground car parks dominate in the city centre. As an example, a section of Neuaubing is shown (see the following figure 2), which is particularly striking in that along Bodenseestraße alone, along a stretch of 1.5 km, as well as in the adjacent commercial area, there are open, ground-level parking areas totalling around 100,000 m².

Figure 2 Neuaubing - Areas totalling around 100,000 m², Generated with *Bayern-Atlas* (2020)

If all these parking spaces could be organised in a bundle - in a collective parking garage - at least 75 % of the space in a four-storey garage could be saved or used for other purposes. This clearly shows how large the space potential can be, as the evaluation in the following chapter also shows. First, Munich's current parking areas are divided into three areas: Open ground-level parking areas, public car parks and residents' parking.

5.2.1. Ground Level Parking Areas

As mentioned at the beginning, a correlation can be established between the urban location of the parking areas and their characteristics. Reasons for this can be the settlement structure, the type of spaces and the offer and network structure of Munich's public transport.

Open ground-level parking areas are mainly found in commercial areas to provide parking spaces for employees, customers and commercial vehicles. These areas are particularly pronounced in the north of Munich along the Frankfurter Ring and especially in the commercial areas above the *Münchner Nordring*, as well as in the already mentioned Neuaubing along Bodenseestraße. Within the middle ring, hardly any distinct parking areas can be identified. This also applies to customer parking spaces at supermarkets and discount stores, as a query on various parking search services such as Parkopedia.de and Google-Maps.de, as well as “HERE” (on 15 December 2020) revealed. Some city-centre shops offer only a few parking spaces in a central multi-storey car park or none at all, such as the “REWE” store in the “FÜNF HÖFEN”. The survey also revealed that the few available retail parking spaces are not accessible at night.

In some cases, the parking spaces recorded also serve the purpose of delivery, temporary storage or other purposes of commercial activities. In the case of customer parking spaces of the retail trade, paths can also serve the delivery of goods, and in the case of parking spaces in commercial areas, larger and heavier vehicles or goods can be parked or delivered in isolated cases.

5.2.2. (Multi-Storey-) Car Parks

The majority of multi-storey car parks are located in Munich's inner city. A search for publicly available parking spaces on Parkopedia.de revealed that the total number of parking spaces in publicly accessible multi-storey car parks within a radius of 3 km around Karlsplatz amounts to around 12,500 (own calculation; query on 20.01.2021). This includes multi-storey car parks without a specific classification and also multi-storey car parks of large hotels, cultural and event venues, department stores and some other areas. During this survey, it was also found that some of Munich's car parks are closed during the night. For example, the car parks of the Karstadt branches in Schwabing and at the main railway station are only open during opening hours. As this is also the case for some other retail car parks found on Parkopedia.de, it is assumed that this is the rule. Outside the inner city area, the settlements become more flat and consequently only multi-storey car parks are found near large shopping centres or stadiums.

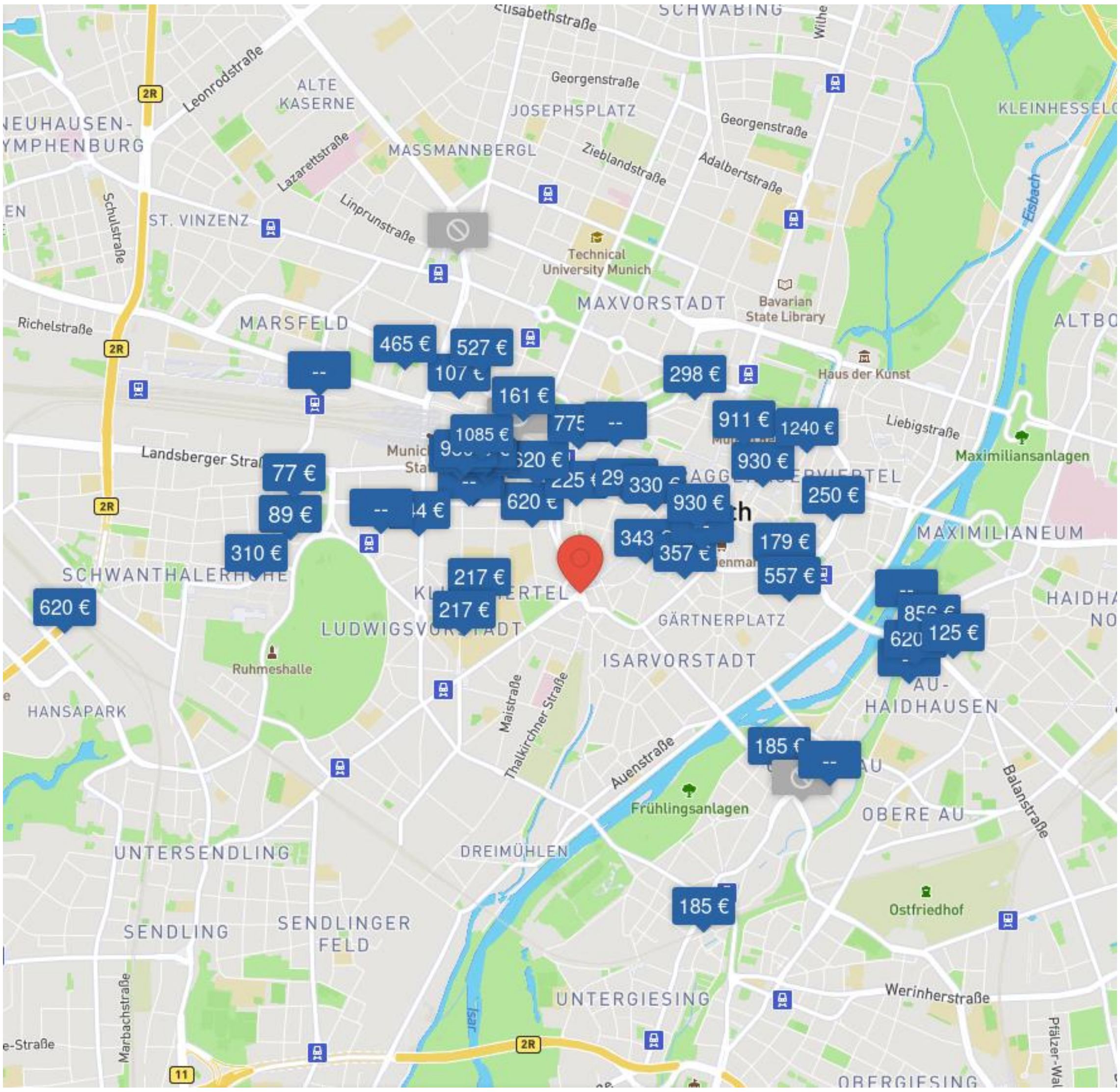


Figure 3 Car parks in Munich city centre, Source: Parkopedia.de (09.01.2021)

The multi-storey car park with the most parking spaces in Munich is the Allianz Arena car park with around 10,000 spaces. It is also permitted to park there outside event times. There is no special regulation for residents' parking (Allianz-Arena, n.d.).

5.2.3. Residents‘ Parking

The majority of Munich's vehicle owners park their vehicles on their own property. As Stjepanovic (2020) explains, the city does not know the exact number of vehicles parked on private property. He explains that the city assumes about 2/3 of all vehicles registered in Munich, whereas about 1/3 of the vehicles park on public property in the street side space. He further explains that this ratio is based on figures from manual counts that regularly take place inside the parking management area. For the new study areas, a similar ratio has been determined, for areas further outside, no determinations are available, but the structures are somewhat looser, Stjepanovic continues.

Parking Management System

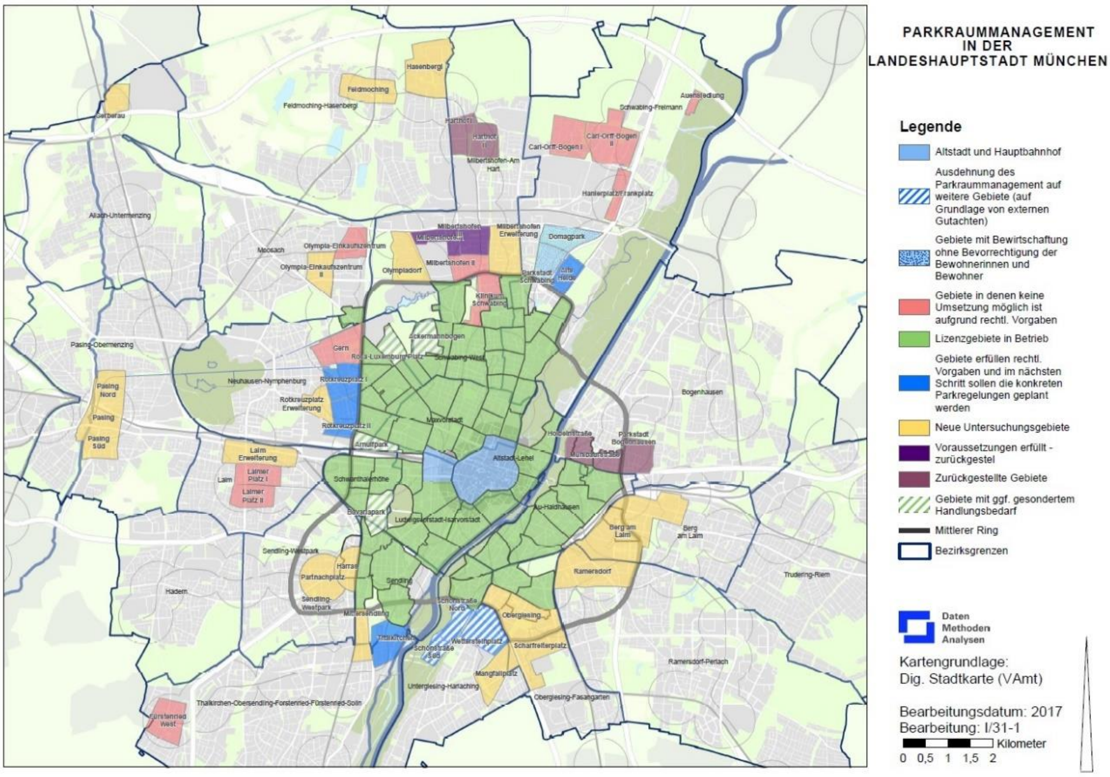


Figure 4 Munich Parking Management Zones, Source: (Landeshauptstadt München, n.d.e)

So far, the more than 60 areas are mainly located within the *Mittlerer Ring*. In the representation X, the middle ring road is shown as a grey line. The current licence areas are shown in green, while new study areas are shown in yellow. The municipality (Stjepanovic, 2020) counts almost 80,000 vehicles on public on-street parking spaces within the existing licence areas, which corresponds to about one third of the vehicles registered there (*Verkehr in München*, 2020). The other two-thirds of the vehicles park - with a few exceptions - in private off-street parking areas on the property of the residence or in residents' collective garages.

Residents' garages

The city of Munich is countering the increase in vehicles with various concepts. One of these is a concept for the construction of residents' garages. In areas with particularly high parking pressure, locations are identified for residents' garages whose construction can be realised by private companies. Within the framework of the "2000 Parking Spaces Programme", the construction is subsidised by 50 percent of the construction costs or up to a maximum of 18,000 euro per parking space. In some particularly cramped neighbourhoods, residents also park in parking garages (Landeshauptstadt München, n.d.). In neighbourhoods with particularly little surface area, underground parking solutions are built. The city of Munich therefore subsidises residents' underground garages up to a subsidy limit of 40,000 euros per parking space (Türck, 2020 reference to the city's "Strategic Implementation Decision"). According to Türck, the construction costs for building underground garages in Munich have risen to such an extent that they often reach or exceed the funding limit. Some of these residents' parking garages are operated by P+R Park & Ride GmbH München. For this purpose, collective underground garages have been created under public squares and public roads. A particularly noteworthy example is the residents' garage under Donnersberger Straße with 284 parking spaces (P+R München, n.d.). It is built in a particularly space-saving variant with an automatic parking system. The main advantage of this system is the space saving compared to conventional underground garages: the long entrance and exit ramp is eliminated or reduced to the transfer cabin, and there is only one central shaft in vehicle width as a "manoeuvring area". According to the manufacturer, more than twice as many parking spaces could be provided in this long elongated volume than in a conventional parking garage with about 110 spaces (Wöhr + Bauer GmbH, n.d.). Only the transfer of the vehicle takes place on the road surface in specially constructed transfer stations, otherwise the space above the ground can be used for other purposes. From there, the car no longer rolls by itself, but is automatically transported to a regular parking space. This project was a pilot project of the city (GIVT mbH, n.d.).

5.3. Area Analysis

The results so far show, on the one hand, that parking pressure is high and, on the other hand, that the parking infrastructure is utilised in a one-sided way. There are many parking spaces citywide that are obviously only in use for about half the day and remain empty throughout the night.

5.3.1. Dual Use (“Shared Parking”)

The city of Munich has become the first city in Germany to launch a pilot trial in which a roadside parking area is designated for shared use. During the day, only bicycles may be parked, at night the parking area is reserved for cars. In this case, university visitors who only need a place for their bike during the day are to be addressed and for the night residents who commute during the day (Landeshauptstadt München, n.d.d).

5.3.2. Road Area

Munich's road surfaces take up the largest share of traffic areas. Around 70 percent of the total traffic area is taken up by roads, cycle paths and footpaths. This corresponds to just under 12 percent of the entire city area (Kizlauskas, 2011). The vast majority of the road network is open-air, the airspace is rarely built over and is not used for other purposes. Since the street areas are already allocated to road traffic and thus to a public owner, they can be redesigned in a joint planning step. The example of Donnersberger Straße shows how new spaces for stationary traffic can be created. In this case, not only a lowering is conceivable, but also a high-rise construction in the airspace of the street surfaces, if the quality of life and the quality of stay of the street is not restricted too much.

In the inner-city area, this is the case if there is sufficient distance to residential buildings. Within the central ring road, buildings are rarely set back and are often not far from or directly adjacent to the traffic infrastructure. Outside the middle ring, and especially in the less dense, outer districts of Munich, high-rise buildings are easier to realise above the road bodies. At the same time, there are other already sealed areas that can serve as new or additional parking spaces, as the example of Neuaubing shows.

It is conceivable to build over Munich's major multi-lane roads outside the city centre. The ends of motorways such as the A8, the A96, but also the A99 motorway ring road and, with some restrictions, sections of federal roads seem suitable.

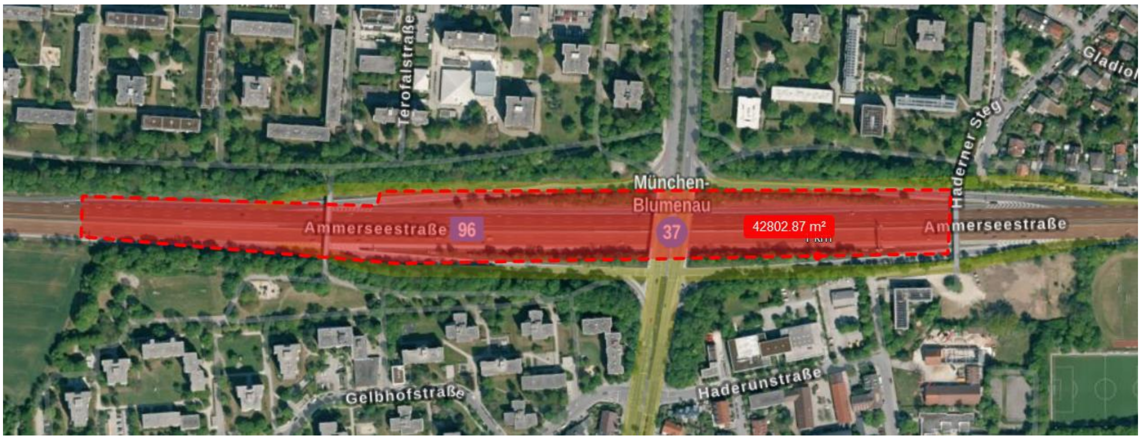


Figure 5 Motorway A96, Munich Blumenau, Generated with Bayern-Atlas (2021)

The A96 motorway extends several kilometres into the residential areas of Munich, has a width of 60 to 80 m in some places, and is surrounded by rows of trees. These locations are therefore suitable for an overbuilding with an elevated garage that can accommodate several hundred to several thousand vehicles (see calculations in chapter 5.4.) and is not immediately perceived as a nuisance.

The end of the A8 motorway is on the western edge of the city, and the settlement that follows further west is loose. A possible overbuilding of the motorway with a long, straight building structure is consequently not in the close field of vision of the residents there and, due to the southern location, does not therefore lead to shading of the residents, which, according to Maget (2021), can cause reservations.

Other possible areas could be motorway interchanges. Their inner surfaces, the loop-shaped entrances and exits, could be suitable for solid foundations. Maget (2021) estimates that the hard boundary conditions such as statics, civil engineering and costs of road superstructures are problematic. This is especially true for complex infrastructure structures such as a motorway interchange.

Maget (2021) determines further potential for road superstructures, since the areas are already sealed and used for traffic. So-called superstructures such as the Bosch multi-storey car park at Stuttgart Airport can also be used as bridges. Maget (2021) also states the benefit as a canopy for cycle paths or as a possibility for adding residential space and greenery. He goes on to say that collective garages should ideally be built close to major traffic generators in order to generate the shortest possible parking trips.

5.3.3. Railway Track Area

On the routes in the north of Munich and also south of the main line, the railway line passes close to commercial and residential areas. Time and again, the track is above ground level and crosses roads in some places. The extent to which such sections of track are suitable for the foundation of the steel girders of the elevated garages requires further investigation. However, the areas are suitable for two reasons. On the one hand, two to four-track lines have a width that is small enough to erect a superstructure without intermediate support (Spreng, 2021). Secondly, some track sections are in close proximity to residential areas and thus to potential users of the elevated garage.

There are huge areas that can be built over on the pronounced track areas between Langwied and the Steinhausen S-Bahn depot in the east of Munich, as well as in the north between Munich Nord Rbf and the Munich-Freimann freight station. Spreng (2021) explains that the airspace of these areas can in principle be built over, but that railway operations and work in the depots must be maintained during the construction phase. According to Spreng and Kühn (2021), this requires compliance with conditions such as railway safety, noise protection, fire protection, decoupling of the structures and train path radio. These conditions also apply during the operation of the elevated garage, Spreng continues. In order to meet parts of these constraints, potential parking areas along cemeteries are not considered in this work. Not every freight railway area is suitable either. At the Riem transhipment station, the airspace is occupied by loading cranes that have to operate above goods trains and trucks. The planning authority for the implementation of such a project lies with the Federal Railway Authority and not with the municipalities.

Ecological assessment

Due to the low surface roughness caused by the medium structural height of the track areas (low height of the railway bodies), the size and length of the areas that merge into continuing railroad streches, these areas always have a special significance for the microclimate. Extensive railroad tracks are generally suitable for the transport of cold air (GEO-NET Umweltconsulting GmbH & Gross, 2014, p. 67). In Nuremberg, for example, it was observed that track areas act as fresh air corridors, bringing colder air from the colder surrounding areas into the denser areas (GEO-NET Umweltconsulting GmbH & Gross, 2014, p. 68). At the same time, the track surfaces also play a significant role in infiltration due to an average degree of sealing of 25 percent (GEO-NET Umweltconsulting GmbH & Gross, 2014, p. 21). Rail tracks also have their own vegetation (Brandes, 2015). Whether there are species worthy of protection on the track surfaces in Munich requires further investigation.

5.3.4. Industrial and Retail Area

Many of Munich's commercial properties such as supermarkets, discounters, shopping centres, warehouses or furniture stores are free-standing, single-storey, flat-roofed and often have an equally large parking area. Both the parking areas and the flat roofs offer a large area potential for overbuilding with stilted buildings or other high storage methods.

Eggeling (2021) notes that not all commercial buildings are designed for large loads and that user acceptance must first be created. He states that long-term parking traffic, especially during peak hours, can disturb both customers and employees of the businesses. He also notes that, depending on the clientele, both traders and customers consistently expect a sufficiently high number of free parking spaces. The example of SportScheck in Kaufinger Straße shows that this can nevertheless work and that different operators can pursue their business on the same floor space on different floors. Eggeling points out that the owner of the in-house underground car park is an external company, with which SportScheck itself is again a tenant.

Retail chains in Germany are increasingly checking their car parks to see if so-called third-party parkers are parking in their customer car parks. This concerns drivers who have parked their vehicles for longer than the maximum permitted parking time. In the meantime, the control of customer parking spaces by parking management companies on behalf of several retail chains is establishing itself (Berninger, 2019). As the parking spaces are owned by the traders, control does not fall under municipal responsibility. Sensor-controlled recording of the occupancy of the parking spaces not only offers the possibility of compiling occupancy statistics, but also automatic monitoring of compliance with the maximum permitted parking time (Köster and Harlos, 2020).

Franz (2021) confirms when asked that parking management is increasingly becoming a focus for the retail company Lidl. In the future, camera-based systems, such as those currently being tested in the Ingolstädter Straße branch in Munich, could also facilitate management. Franz explains that active management of sufficient parking spaces is still necessary even in large cities, as many customers, especially in the outer city districts such as Trudering-Riem, still predominantly come by car. Shared parking is therefore conceivable in the future, since on the one hand parking spaces are still needed for customers and on the other hand, through the further development of parking space management, a more targeted release for third-party parkers can be issued, Franz continues. He goes on to explain that it must be ensured that sufficient parking spaces are available again in the morning when the shops open and that, at the same time, the availability of parking spaces in the evening hours between closing time and closing time remains very important for traders. Consequently, conflicts can arise in these areas in the evening hours when "shared parking" is operated, as residents already return while customers continue to claim parking spaces.

Building over commercial space has the great advantage that in the vast majority of cases it is already sealed, or at least the soil no longer has any particular ecological function. A good road connection for a larger volume of traffic, as is to be expected in the case of a collective garage, is already given for commercial sites and may only need to be partially reinforced. Often there is already a local public transport connection that employees and customers can use. Overall, the negative ecological consequences of the realisation of parking garages on commercial sites are estimated to be low.

5.3.5. Office Complexes

Office buildings themselves are usually not particularly suitable for building over. The vast majority of office buildings in Munich, such as BMW or Siemens, are neither low nor with a large rectangular roof. What can be suitable is the use of the employee car parks such as the BMW employee car park "Lemgo" in Milbertshofen or the Siemens car park in Munich Perlach with an area of around 100,000 sqm. Eggeling (2021) points out that user acceptance must be given especially to office workers who feel disturbed by noise from parked cars. Compared to other commercial areas, the sensitivity has to be taken into account even more. Furthermore, however, employee parking spaces are also unused outside working hours. And that is exactly the period of time when residents have to park their vehicles.

5.3.6. Agricultural Area

Agricultural land is the easiest to plan and build on. On the one hand, this is due to the fact that there is still a relatively large amount of such land directly between settlement areas in Munich and that it is also easily accessible. And on the other hand, that alternative areas free of settlements - apart from company premises - are hardly of the same size. The decisive advantage, however, is undoubtedly that concepts can be created and implemented very quickly for agricultural land, as no demolition work has to take place.

In contrast to areas in central or northern Germany, the cultivation areas in and around Munich are small (Baden-Württemberg, 2010, p. 8). Nevertheless, some are located in the immediate vicinity of settlements or surrounded by settlements or commercial areas. The loss of this land for regional agriculture would weaken it and increase the already existing pressure on the remaining small farmers. Simultaneously with the loss for the farmers, Munich's regional supply would also be weakened. In addition, arable land also has ecological functions such as: Seepage area, open space for human vision and crossover area as well as habitat for species such as birds or field hamsters. Before an unsealed area is sealed, the quality of the soil must be examined and, if necessary, the soil must be specially protected. Revitalising a soil is costly and therefore existing vital soils are worth protecting (Landesamt für Umwelt, Landwirtschaft und Geologie, Freistaat Sachsen, n.d.). It should also be checked whether the area is located in a fresh air corridor.

Most farmland does not offer a connection that meets the requirements for a collective garage with a large volume of traffic. For this, the traffic routes would have to be additionally expanded. In addition, it also has an impact on small-scale regional agriculture, which is already under threat. Because of the disadvantages of planning agricultural land, this paper will only include a few of these areas for lack of alternative land. Therefore, the majority of solutions that are more difficult to implement were planned on commercially used land.

5.3.7. Brownfields

At first glance, brownfield sites appear to be very attractive for the development of new building plans. However, it currently seems unrealistic in Munich that today's brownfield sites can be developed for pure parking. Large brownfield sites along the tracks at Ostbahnhof or Viehhof, as well as the Großmarkthalle, have already been planned (Krass, 2020, 2021; Landeshauptstadt München, 2019). The exact use of the other areas can only be guessed at from the map material (OpenStreetMap, Google-Maps, Bayern-Atlas). Therefore, this category does not play any further role in the present work.

5.3.8. Other Areas

In addition to private commercial space, the Munich public utility company, for example, also operates large areas to store public transport vehicles. Since these areas are already owned by a municipal company, it may be easier to vote to build over these areas and put them to additional use. The areas at the Leuchtenbergring and Westendstraße stops are particularly pronounced, with a total of 150,000 sqm of ground area.

Streifeneder (2021) can also imagine building on areas with sports fields and placing the playing fields on the roof of the multi-storey car park. These areas were not considered for further consideration due to their possible function as infiltration areas.

5.3.9. Results

In total, as already mentioned, a little over 3 km² (see also Appendix II) of areas have been found, which are divided into different types. The largest potential areas are track areas, followed by existing open parking areas and commercial building areas that can be built over. Based on a concise ecological assessment, a ranking is also provided in table 1. The higher the rank, the smaller the encroachment on ecological structures and functions. It has also been shown that the ownership structure varies. While private companies can be more risk-averse and quicker to implement, a public owner can plan his own areas in a decision through political objectives.

Table 1 Identified areas: types, owners and ecological note

Type	**Potential [m²]**	**Owner**	**Ecology**	**Rank**
Road Area	352,832	Public	Surface Roughness	3
Railroad track Area	1,089,350,7	DB Netze AG	Infiltration, Fresh Air Corridor	5
Industrial Area	743,983.9	Private	Surface Roughness	6
Industrial Area (Public Owned)		Public (few)	Surface Roughness	4
Brownfield	-	Private / Public	Surface Roughness, Other	7
Parking Area (Industrial, Office, Others)	823,819.5	Private / Public	-	1
Car Park	13,843.6	Private / Public	Surface Roughness	2
Agric. Area	-	Private	-	8
Playing Field	-	Private / Public	(Infiltration, Reflection)	-

In the following figure (see figure 6), all identified areas are shown geographically and differentiated by colour. Track areas are shown in green, road areas in red, commercial areas in black and parking areas in blue. Areas belonging to the municipal utilities are coloured orange. Further area types as well as the exact area size and coordinates can be found in the appendix to this work.

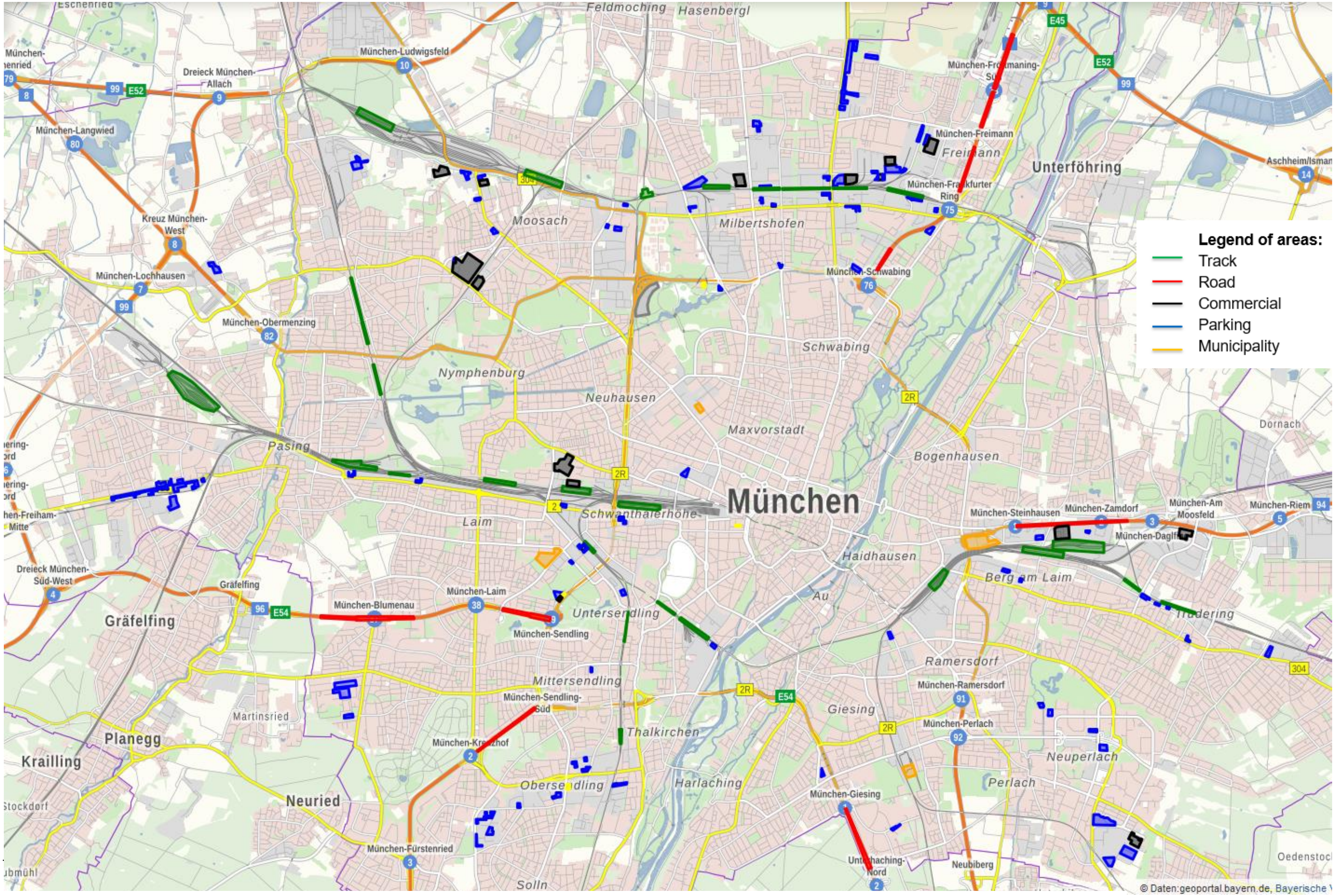


Figure 6 Recorded areas with potential for parking, Source: Bayern-Atlas (2021)

5.4. Dimensioning of Collective Garages

In order to park the identified areas as efficiently as possible, parking systems are compared and solutions are worked out in the following. Compared to conventional parking garages, car parks with automatic parking systems have space advantages.

A conventional car park has a standard width of 16 metres to accommodate two vehicles (see Figure 7). Parking in the second or third row is not possible without autonomous driving and without controlling many vehicles individually.

Figure 7 Usual width of a car park unit, Source: Astron Parkbau, n.d. (https://astron-parkhausbau.de/haeufige-fragen-faq/wie-dimensioniert-man-das-parksystem)

The manufacturer Lödige states that automatic parking systems are up to 60 percent more space-efficient than conventional ones (Lödige Industries, n.d.b). Rosendahl (2021) estimates the space efficiency to be lower, but still with a positive balance.

For the parking areas in Munich, work is therefore being done with an automatic parking system that does not currently exist on this scale. The dimensioning is an idea of the author and has never been realised in this dimension before.

For the calculation of the collective garages, this work is based on the MULTIPARKER 730 system from the company Wöhr, which also implemented the parking garage in Donnersberger Straße (here with the MULTIPARKER 740 system). It is initially assumed that a system unit with a width of around 40 metres can accommodate three rows of vehicles on each side of the transport shaft (see following figure 8). Likewise, a lightweight steel construction is assumed to be able to hold several parking decks as well as being flexible and light enough to build over existing buildings without major intervention in them.

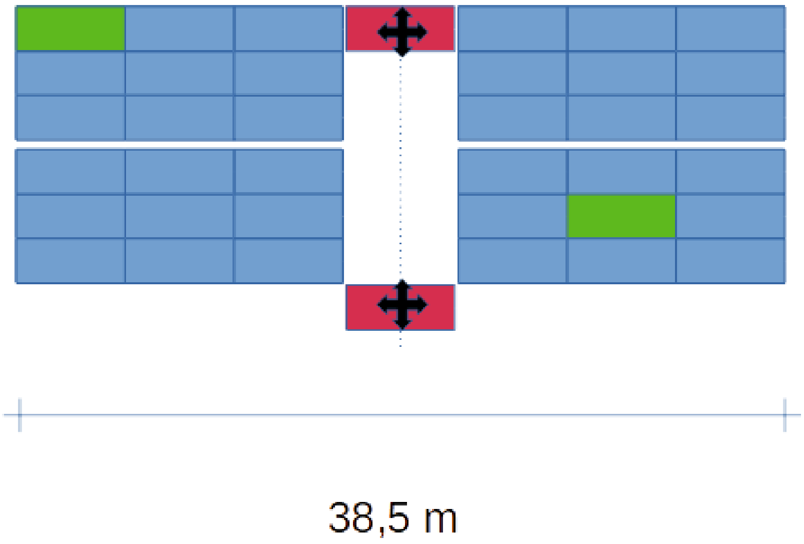


Figure 8 Inner of an automatic parking garage unit

In total, such a unit can be up to 100 metres long and a height of more than 30 metres is not inconceivable, according to Rosendahl (2021). In the centre is a conveyor shaft, continuous in length and height, which brings the vehicles into the system unit and out again. On both sides, to the left and right, there are three rows of vehicle pallets, all of which can be accessed by moving the pallets. Depending on the location, the available floor space and the position of the collective garage, the system units are placed next to each other and in a row, as well as connected to each other in a row. A continuous tunnel for transport across several system units can be created on the roof of the building above the conveyor shafts. The transport with vehicles and the return of empty pallets takes place via these additional tunnels. This could further increase the access time.

In order to calculate the lengths, widths and heights of the individual parking spaces per vehicle, the typical vehicle sizes of the individual vehicle segments were researched for this work. The focus is on the proportion of new registrations and the average dimensions. (see following table).

Table 2 Dimension per Segment and Trend, Source (Kraftfahrt-Bundesamt (KBA)- Federal Motor Transport Authority, n. d.),(Kraftfahrtbundesamt, n.d.)

Segment	**Share [%] 2018**	**Width (Without Side Mirror)**	**Length**	**Hight**	**Exemplary**	**Year of Manu-facture**	**Trend**
Mini (A)	6.7	1.65	3.54	1.48	VW-up (3 doors)	2011	Stable
Small (B)	14.5	1.76	4	1.43	Opel Corsa E	2019	Stable
Medium / large (C,D,E)	32.9	1.79	4.28	1.46	VW Golf	2020	Diverse
Multipurpose (M), (Vans)	6.3	1.9	4.85	1.75	VW Sharan	2010	Negative
Luxury (F), Sports (S)	5.5	1.9	5.12	1.5	S-Class	2013	Positive
SUV / Off-Road (J)	27.1	2	5.15	1.8	BMW X7	2019	Positive
Others	7	-	-	-	-	-	-
Total	93	-	-	-	-	-	-

In addition to political regulations and subsidy programmes, the preferences of buyers are also decisive for estimating a possible future development of the size of vehicles. Compared to the previous year 2017, registrations of premium vehicles in the upper vehicle segments have increased, while the share of vans and compact cars has decreased. At the same time, the small and mini vehicle segment is experiencing a comeback due to the increasing availability of electric vehicles, which are heavily subsidised in Germany. The fixed subsidy makes the smallest vehicles in particular the best deal, which can also be deduced from the official registration figures at the end of 2020 (Kraftfahrt-Bundesamt (KBA)- Federal Motor Transport Authority, n.d.).

It is therefore assumed that a mixed market will continue to present itself in the coming years, in which both small cars and larger vehicles will be represented.

As a simplification, segments A to E are assigned to a “type A”, which represents the smaller vehicles, and the other segments listed in the table to a “type B”, which represents the larger vehicles (see Table 2).

Table 3 Defining two types of car segments

	Share bundled [%]	**Width [m]**	**Length [m]**	**Hight [m]**	**Ground area [m²]**	**Volume [m³]**
Type A	54.1	1.8	4.5	1.6	8.1	12.96
Type B	38.9	2.2	5.3	2	11.66	23.32
Mean	100 % (50:50)	2	4.95	1.8	9.88	18.14

With the exterior mirrors folded in and a few centimetres of buffer, “type A” vehicles can be set to a maximum width of 1.8 m. These vehicles are no longer than 4 to 4.5 m in length and no more than 1.5 m in height. For “type B”, somewhat larger dimensions apply accordingly, whereby the BMW X7, for example, can be counted among the vehicles with the largest external dimensions of all segments. A few centimetres are added to the height for the roof aerial. Divided into two or three types, different pallet sizes can be planned for the collective garages in order to design the area and space as efficiently as possible.

Although “type A” segments dominate new registrations, a ratio of 50:50 is assumed for planning a shared collective garage in this paper. Accordingly, one system unit of type A and one system unit of “type B” is assumed for each location, whereby no distinction is made in the actual external dimensions of the overall building according to the arrangement of the respective type in the building. For simplicity's sake, the average value is therefore always used.

The following table serves for dimensioning. It gives an overview of how many vehicles can be accommodated for a defined volume. The construction dimensions of the facilities, the building envelopes and the vehicles are included. The heights are rounded off so that no half storeys are planned. A buffer of 10 percent is also added to the calculation to allow for any irregularities in the edges of the area and other risk factors. The so-called "cabs" are average pallet volumes on which the vehicles are finally placed.

From all these input data, an average factor has been determined, with which it can be calculated how many vehicles can stand net on a certain area and with a certain number of levels.

Factor: 0.057 [-]

It is assumed that in dense inner city areas smaller potential areas are available than in suburban areas and the building height should not exceed 20-25 m. The dimensioning of the technical construction is based on information from the technical drawings of the company Wöhr and on own considerations (Wöhr, n.d.).

The areas found can be examined on the basis of this calculation. The following investigation is presented as an example. In order to test the idea of a collective garage per district, the areas found are examined according to defined area type, possible area, possible height (number of storeys). As can be seen (in table 5), the districts of Altstadt-Lehel, Ludwigsvorstadt and Untergiesing - Harlaching are not suitable. Ground areas of less than 3,000 m² are not considered as they are too small for the project.

Assuming that all on-street parked vehicles in Munich, as well as all other vehicles within the *Mittlere Ring* and the net commuters are to be accommodated in collective garages, this would be a rough estimate of 624,000 vehicles (see calculation below). The total capacity of the designed collective garages is also based on the following table (see table 5).

Calculation: 0.3 x 800,000 + 0.7 x 220,000 + 230,000 = 624,000 vehicles

Explanation: 30 percent of 800,000 Munich's vehicles parking on-street + 220,000 vehicles parking within the Mittlere Ring (the remaining 70 percent, as 30 percent have already been taken into account) + 230,000 commuters = 624,000 vehicles in total

Table 4 Dimensioning of Automatic Parking Garages

			Building					Tech. Construction			Cab					Vehicles	
	Lenght	Width	Height	Ground Area	Floors	Rou	Lenght buffer	Latural	Net Ground Are	Height Floor	Lenght	Width	Total Area	V / n	n	90 %	Factor
Urban	50	25	15	1,250	6	6	3	0.6	1,115	2.5	2.2	6.5	16,725	35.8	468	421	0.056
	100	50	20	5,000	8	8	8	0.6	4,600	2.5	2.2	6.5	92,000	35.8	2,573	2,316	0.058
	100	100	15	10,000	6	6	8	0.6	9,200	2.5	2.2	6.5	138,000	35.8	3,860	3,474	0.058
	100	100	25	10,000	10	10	8	0.6	9,140	2.5	2.2	6.5	228,500	35.8	6,392	5,752	0.058
Suburban	200	100	5	20,000	2	2	19	0.6	18,040	2.5	2.2	6.5	90,200	35.8	2,523	2,271	0.057
	200	100	10	20,000	4	4	19	0.6	18,100	2.5	2.2	6.5	181,000	35.8	5,063	4,557	0.057
	200	100	25	20,000	10	10	19	0.6	18,040	2.5	2.2	6.5	451,000	35.8	12,615	11,354	0.057
	200	100	30	20,000	12	12	19	0.6	18,100	2.5	2.2	6.5	543,000	35.8	15,189	13,670	0.057
	200	200	25	40,000	10	10	19	0.6	36,140	2.5	2.2	6.5	903,500	35.8	25,273	22,745	0.057
	200	200	35	40,000	14	14	19	0.6	36,200	2.5	2.2	6.5	1,267,000	35.8	35,441	31,897	0.057
	400	400	25	160,000	10	10	38	0.6	144,800	2.5	2.2	6.5	3,620,000	35.8	101,259	91,133	0.057
	400	400	30	160,000	12	12	38	0.6	144,800	2.5	2.2	6.5	4,344,000	35.8	121,510	109,359	0.057
	1000	410	25	410,000	10	10	57	0.6	386,630	2.5	2.2	6.5	9,665,750	35.8	270,371	243,334	0.059
Suburban (flat)	200	100	5	20,000	2	2	19	0.6	18,100	2.5	2.2	6.5	90,500	35.8	2,531	2,278	0.057
	500	100	5	50,000	2	2	57	0.6	44,300	2.5	2.2	6.5	221,500	35.8	6,196	5,576	0.056
	1000	200	7.5	200,000	3	3	57	0.6	188,540	2.5	2.2	6.5	1,414,050	35.8	39,554	35,598	0.059
	1000	220	5	220,000	2	2	57	0.6	207,460	2.5	2.2	6.5	1,037,300	35.8	29,015	26,114	0.059
																Average	**0.057**

Table 5 Dimensioning of 24 Garages (Scenario 3 and 4; (Hint: different factor used: 0,058))

	District	Description	Area [m²]	Floors	Vehicles	Coordinates [GK4]	
1	Altstadt Lehel				0		
2	Ludwigsvorstadt – Isarvorstadt				0		
3	Maxvorstadt	waste land	6,800	4	1,578	4466746	5334454
4	Schwabing West	mall	4,900	2	568	4467538	5335853
5	Au – Haidhausen	railway tracks	90,000	3	15,660	4470667	5332361
6	Sendling	railway track, parking spaces	40,000	3	6,960	4465971	5332034
7	Sendling – Westpark	parking area (MVG, private), track area	170,000	3	29,580	4464790	5333110
8	Schwantalerhöhe	track area	157,000	3	27,318	4465746	5333742
9	Neuhausen – Nymphenburg	parking area (Deutsche Post) and nearby track area	130,000	4	30,160	4464585	5334536
10	Moosach	waste land, railway track	20,000	4	4,640	4463247	5337867
10	Moosach	Nord Rbf	900,000	4	208,800	4464556	5339199
11	Milbertshofen – Am Hart	railway, parking and industrial area	170,000	2	19,720	4469188	5339296
12	Schwabing – Freimann	gasoline station, parking space	20,400	5	5,916	4469577	5337760
12	Schwabing – Freimann	P&R parking area Studentenstadt	9,000	5	2,610	4470964	5338501
13	Bogenhausen	MVG depot, Dachser, parking area	150,000	3	26,100	4471654	5333296
14	Berg am Laim	railway tracks	350,000	3	60,900	4472777	5332919
15	Trudering Riem	parking space, railway track	70,000	3	12,180	4474778	5332088
16	Ramersdorf – Perlach	industrial area near railway	20,000	2	2,320	4472409	5328374
17	Obergiesing	track area	10,000	2	1,160	4470307	5329348
18	Untergiesing – Harlaching				0		
19	Thalkirchen – Obersendling – Forstenried – Fürstenried	industrial area, markets	26,000	3	4,524	4463301	5328262
20	Hadern	parking area	96,660	6	33,638	4461048	5330716
21	Pasing – Obermenzing	railway operation station	84,600	3	14,720	4458046	5335651
22	Aubing – Lochhausen – Langwied	highway (parts of Obermenzing)	400,000	3	69,600	4458792	5337404
23	Allach – Untermenzing	parking area	33,710	6	11,731	4460933	5339695
24	Feldmoching – Hasenbergl	parking area	73,000	6	25,404	4467425	5339505
25	Laim	mvg depot	60,000	3	10,440	4464549	5333030
	Factor used		0.058				
	Vehicles in total				**626,227**		

5.5. Modelling

5.5.1. Concept

As already noted in the methodology chapter, the simulation serves to quantify the effects that autonomous parking in collective garages has on traffic. The focus is on the analysis of trip lengths and the effects on congestion on certain busy road sections in Munich and in the overall traffic situation. Only passenger cars are simulated and it is assumed for the entire modelling that the traffic situation with autonomous vehicles behaves like the traffic situation today. The simple reason for this is that it is not possible to estimate how traffic will change, nor would there be any comparability with the project of this work - the addition of garage trips.

The study region covers the urban area of the state capital Munich, within which all trips are recorded that have at least one starting point, one intermediate destination or one end point within this area.

Different scenarios are designed that can be compared with each other.

Scenario 0: Motorised individual transport as we have today (state of the art)

This scenario represents the traffic in the study region as it might occur on a normal day in the present day. This model also represents the basic scenario, as all other scenarios are based on this transport model and complement it. Therefore, it is also called Scenario 0.

Scenario 1: Motorised private transport as today, but with one large collective parking garage

In the second scenario, it is assumed that all of Munich's on-street parked vehicles will from now on be housed in a very large collective garage. As shown in the following figure, the track area of the Langwied facility is particularly suitable for this. Although the track areas of the Munich Nord Rbf and in Berg am Laim with the Steinhausen S-Bahn station are larger, an area outside but close to the residential areas was deliberately chosen.

Figure 9 Aerial view of the track area in Langwied, Source: Bayern-Atlas (2020)

Scenario 2: Motorised individual transport as today, but with two large collective car parks

In the third scenario, it is assumed that all on-street parked vehicles in Munich are distributed between two large collective garages (one in the west and one in the east). The choice falls on these two areas precisely because of the possibility of geographical differentiation (see upcoming figure).

Scenario 3: Motorised individual transport as today, but with 24 collective car parking garages

Scenario number 3 provides for shorter distances to the collective parking garages and therefore the number of garages is increased to 24, which are distributed as evenly as possible over the entire city area in order to generate the shortest possible parking distances. There are no suitable larger spaces in the districts of Altstadt Lehel, Ludwigvorstadt - Isarvorstadt, Untergiesing - Harlaching, so three additional spaces from other districts are added to the list.

Scenario 4: No more on-street parking in the city centre: Park & Ride

This scenario differs from the others. In addition, a city centre area is defined in which no more parking spaces for long-term parking are provided. Residents and visitors of this area park their vehicles in a park and ride collective garage outside this area. The journeys between this park and ride facility and the location within the area are made using environmental transport and are therefore not represented in the modelling.

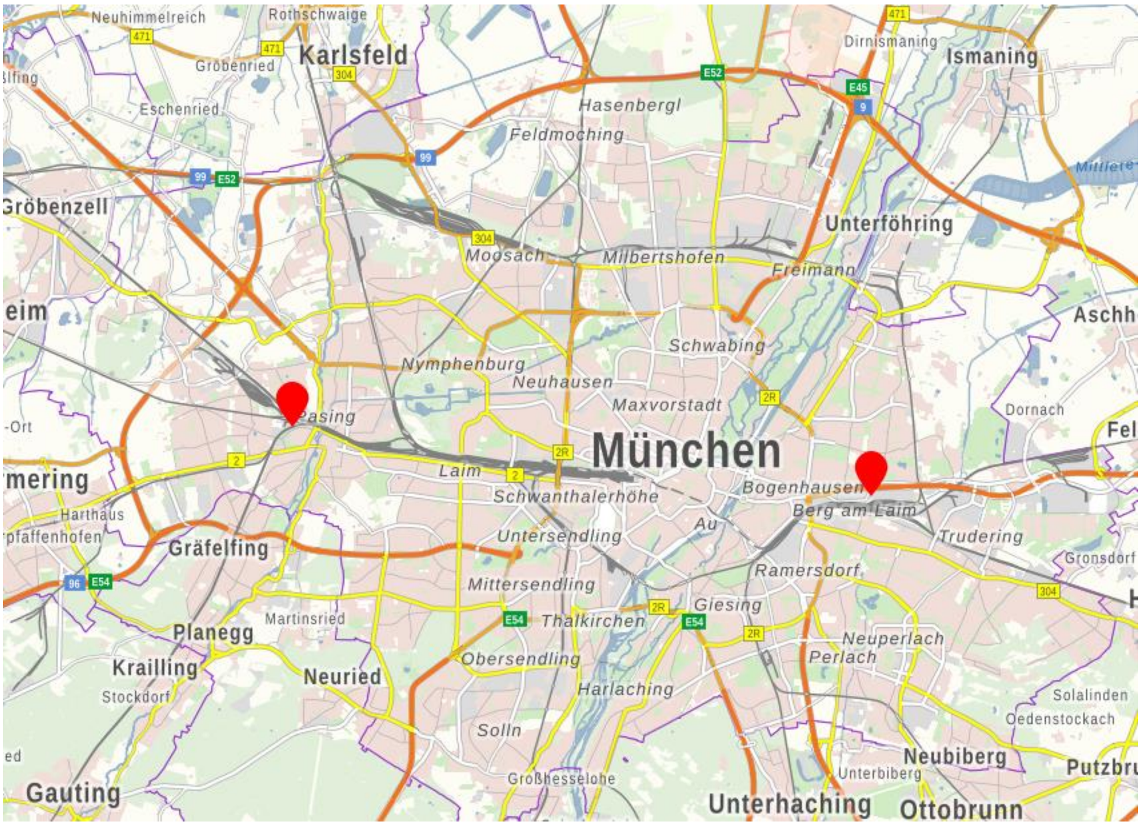


Figure 10 Locations of the "two-garage" scenario, Source: Bayern-Atlas (2021)

5.5.2. Preparation and Background

In order to reduce the runtime of the simulation, the input data sets are reduced in size. Two main methods are used for this:

- Scaling
- Simplification (removal of all irrelevant parts of the population).

The first step of the adjustment was the possibility to scale down the population (plans). llorca and Moeckel (2019) investigated the effect of downscaling for this application and found that with a scale factor of, for example, 5 percent, similarly valid results can be obtained as with the simulation of the full population without scale factor. For this purpose, I was provided with a corresponding population from the Spatial Mobility Modelling Research Group.

For the simulation of the effects of parking trips, all traffic modes other than car are irrelevant and are therefore removed from the plans at the beginning. For simulation purposes, bus traffic also takes place on a separate road network and therefore has no influence whatsoever on the traffic patterns of the car trips. Due to the small number of public transport vehicles, their influence on the traffic pattern of individual traffic can be regarded as extremely low. Since the simulation is primarily concerned with the changed traffic patterns of individual traffic, this effect can be neglected. Conversely, however, there might be an effect that unfortunately cannot be measured with this setting of the simulation. For the Parking Free Munich City Centre scenario, a centre is assumed that fully covers some inner city districts and neglects other sub-districts. This is due to the cut of the input data and the shapefiles of the city districts, for which it is simplified to assume that only complete city districts can be read in. Thus, the area within the *Mittlere Ring* is not completely covered and in particular the areas of northern Giesing and eastern Neuhausen - Nymphenburg are missing. The exact description can be found in the corresponding subchapter.

5.5.3. Implementation

To change a plan, a new plan has to be written, which contains new elements and also all old elements to be taken over. To do this, the structure of the plans is analysed. The structure of the provided plan file always starts from the trips that are to be undertaken. The plan of a "person" starts with the end of an activity and ends, when the last trip is over, with the starting point of the last activity of the plan. Therefore, garages cannot be directly assigned to an activity, but must be added to the plan as a separate activity (see also figure 9). If, for example, a plan contains two trips to bring a "person" from the activity "home" to the activity "work" and back again, then usually only the end time of the first activity is known, while no time information is stored for the last activity. It starts when the trip (however long it lasts) is over. This results in two problems.

On the one hand, it is not yet known how long the vehicles need for the trip from the garage to the location of the first activity. Therefore, no fixed starting time at the garage can be defined. The structure of the plans file, however, requires a stored time for all activities (except the last one). The new first activity "Garage" also needs a stored time for a second reason, because the vehicle must arrive punctually at the location of the first activity in order to be able to keep to the schedule of the plan.

> Technical background: Each person's plan always begins and ends with an activity. Time specifications are assigned to it, such as start time, end time or duration. The activities are inevitably connected by legs whose duration is later determined by the simulation.

On the other hand, the last activity so far (in this example in the graph it is the second "home") becomes the new penultimate activity and also requires a new time entry. Here, too, neither the start nor the end time can be entered, since the time of the return home depends on the duration of the pre-scheduled trip and thus on the traffic.

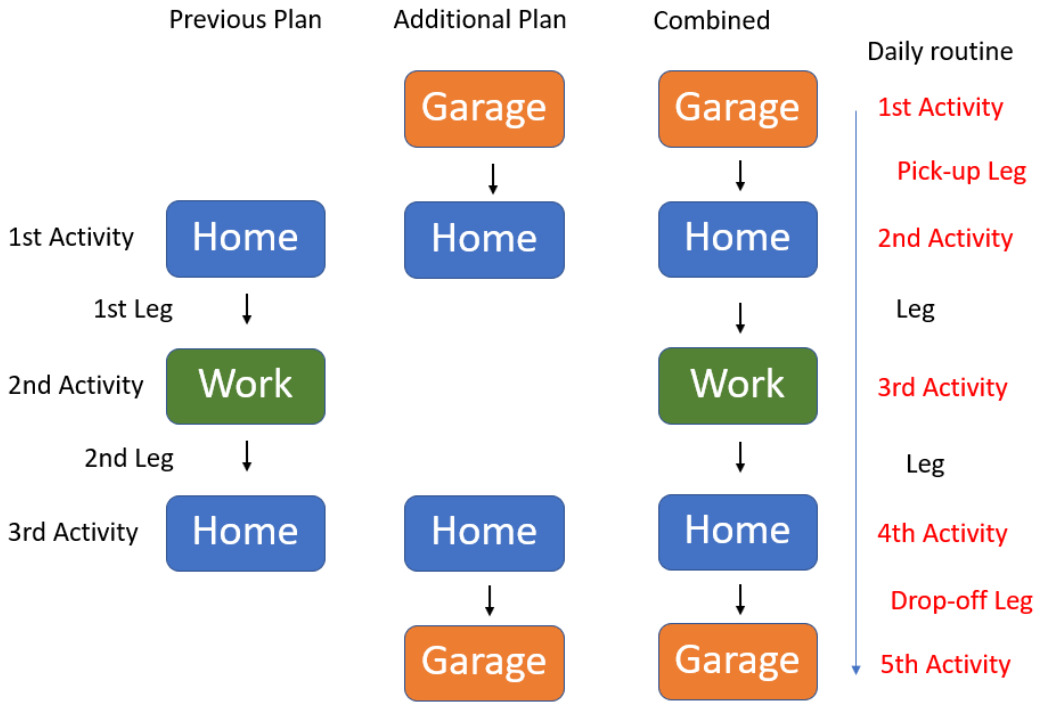


Figure 11 Comparison of two alternative concepts

Solution Approach

A simple solution to this problem is to add the garage trips as separate plans. The existing plans are not affected and the trips from the garages to an activity as well as the trips from the last activity to the garages can be created according to a randomised pattern. The trips can generate additional traffic in a simulation and thus be taken into account in the traffic pattern. However, this solution contains the great uncertainty that the garage trips according to a randomised pattern are not matched to the traffic flows to be simulated. They are added without having determined when the individual trips will actually occur.

An alternative approach is to analyse when peak congestion usually occurs and when commuters and other trips usually start and end to which garage trips can be assigned. Based on this, start times and coordinates for the garage trips can be estimated to write the plans.

For example, if after-work traffic with significant delays in traffic flow occurs especially between 4 and 6 p.m., the focus can be placed on trips in these two hours with a buffer for trips that start before and end after. It also matters how long parking trips take. Using the results of a previously conducted simulation, both coordinates and arrival times can be determined, which are then filtered to obtain the trips for which a subsequent parking allocation is sought. The arrival times then serve as departure times for the parking trips. In order to be able to consider the influence of the parking trips on the overall traffic in time for the start of the evening rush hour, parking trips before (in this example) 4 p.m. that find their destination after 4 p.m. are also taken into account. In this way, the reciprocal effect of the additional parking traffic on the existing traffic can be taken into account. This model is transferable to all times of the day and also to the entire day and works analogously for trips from the parking garage to a location where a trip is to begin. The disadvantage of this model is the uncertainty of the actual arrival of a vehicle after a parking trip at the activity, as well as the actual departure time after a regular trip (at the end of a schedule). The delay of the preceding parking trip (pick-up) does not affect the start time and subsequently the end time of the regular trip. This leads to distortions. This is because if the traffic flow on the roads changes due to the traffic generation of the previous trips, then additionally created, rigidly fixed garage trips will influence the traffic flow at a different point in the road network and at a different time. This may result in new congestion peaks that could be created by the additionally induced garage trips not being detected. It is assumed that these distortions are not large, but in order to be able to simulate a stringent process, this approach is not used.

Chosen Procedure

To avoid this problem, a second way is chosen in which the garage trips are added to the previous plans at the location where they actually occur. To determine the start time of the pick-up leg at the activity “Garage 1”, a general average travel time between two locations was calculated. For this purpose, the Euclidean distance between “Garage 1” and “Home 1” was determined with the help of a function and divided by an assumed average speed of 30 km/h. The calculated time duration was subtracted from the ending time of “Home 1” and the earlier time determined from the time difference was set as the ending time of “Garage 1”.

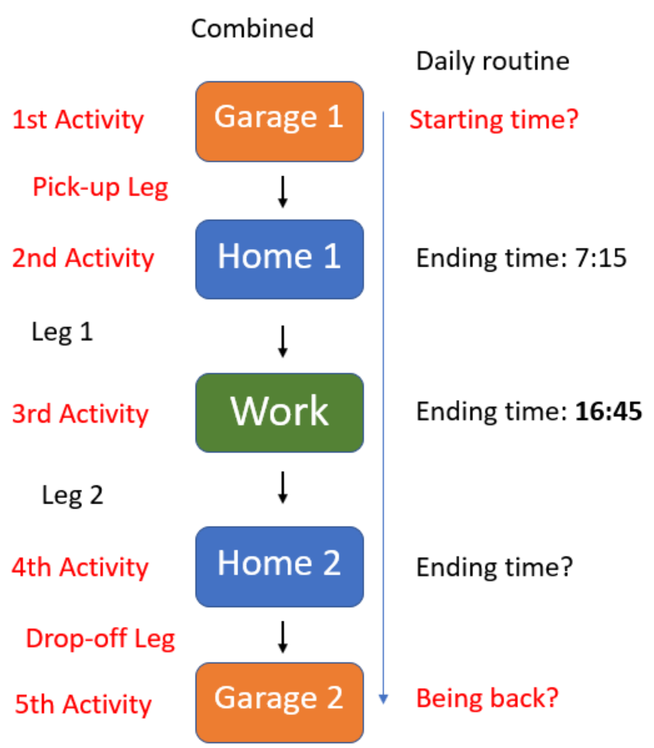


Figure 12 Adjustment of the time attributes

In order to add the garage trip at the end of a plan, a time attribute is added to the last activity of the old plan. Since the end and start time are again unknown, the value "duration" is used, which is measured as 60 seconds. The last activity of the old plan mentally becomes a drop-off point where the vehicle has a short stay before it drives into the garage to the new last activity of the plan. The “*mode* = *car”* was assigned to the four legs so that the simulation knows on which network the movement should take place.

A not insignificant proportion of persons in the total population file only have one change of location within their plans. That means for the example plan, the person does not return to its original location. In this case, the second parking trip respectively the second garage is added to the second activity. Compared to the exemplary representation of the previous figure, the third activity "Home 2" is omitted and the choice of garage depends on the location of the second activity. In the scenarios with several garages, "Garage 2" is often a garage with a different location than the first. This case also applies to all subsequent modifications of the plans.

Consideration of an intermediate garage

Similarly, it is clear from the input plans that a not insignificant proportion of the population stays at a destination for more than two hours until the return journey begins. The idea is that short-stay parkers (< 2h) are accommodated in a short-stay car park, as the effort to send and retrieve these vehicles to a possibly distant parking collective garage is too great. Conversely, this means that all plans with a longer stay of 2 hours or more (>= 2h) in Munich must be assigned a garage. To implement this, two additional destinations must be added. The vehicle drops the person off at the destination as usual and drives to a garage, from where it returns to the destination to pick up the person. In the case of the example person, the person is dropped off at the workplace and also picked up there on time. For writing the combined schedule, this means not only adding two additional activities, but also two new legs. Previously, only the time when the person leaves the first "Home" was known, as well as the time when the person leaves the workplace. Also, as described before, a solution was found for the garages at the beginning and at the end of the plan.

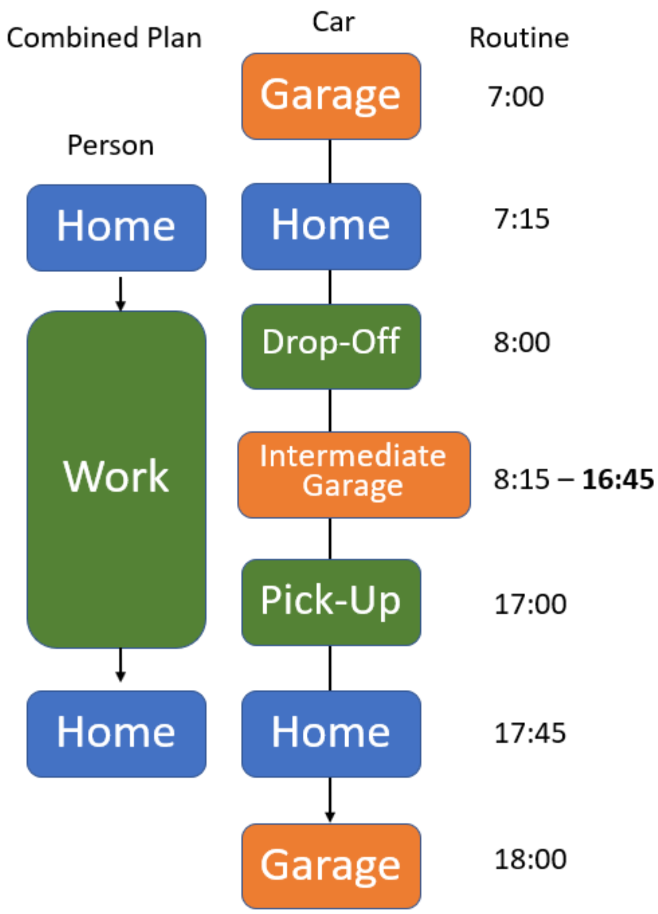


Figure 13 Implementation of adding an intermediate garage

The arrival time at the "Drop-Off" point is determined by the simulation or depends on the traffic situation. Since it can be assumed that the drop-off relationship does not last long, a "duration" can again be set as the time value. In this case, 60 seconds is again assumed. The arrival time at the intermediate garage is again dependent on the departure time at the drop-off point or the traffic situation on this journey. The time of departure at the intermediate garage must be written back into the plan as the end time of this activity "Intermediate Garage". The vehicle should not be at the workplace too early and if possible not too late and should leave the garage at a realistic time. Here, the function of calculating the Euclidean distance, which is divided by an average speed of 30 km/h, is used again to estimate the journey time. This time is subtracted from the known end time of the stay at the workplace to be able to write an end time for the activity of the intermediate garage.

Since there are at least two hours between dropping off and picking up the person, it can be assumed that the two durations of the two parking trips are rarely longer than the person's stay at his destination. The example person can therefore leave his workplace at a known time and make his way home. The activity of the destination (in this case the workplace) can be transferred to the new combined plan as a "pick-up activity", since no start time is written in this activity, but an end time and the coordinates, as well as the type of activity. This is also the data that is relevant for the combined plan at this point in the plan.

Allocating garages and considering off-street resident parking

The dimensioning of the garages is based on the methodology of the previous subchapter. It is assumed that the vehicles arrive in space-efficient collective parking garages at locations that are able to accommodate the respective number of vehicles to be parked. In each case, the garage with the shortest Euclidean distance to the activity is assigned. For this purpose, depending on the scenario, a list of possible garage locations and their capacity is taken into account, which is queried when assigning the garages. In the case of the scenario with one garage, one garage is listed that has the capacity to accommodate all vehicles with parking needs. In the scenarios with multiple garages, the capacity can be spread over several locations and the vehicles can each be assigned to the garage with the shortest distance. When a garage is fully occupied, the next possible garage is added to the plan. The properties of the garage list, with locations and capacities of the garages, correspond to those actually determined in the previous chapter.

As already stated at the beginning of the chapter “Case Study”, about 2/3 of all residents of Munich have access to a private parking space. No garage needs to be provided for them. It is therefore assumed that for at least 30 percent of the trips a garage allocation must take place. Furthermore, it is assumed that the condition described above with the intermediate garages applies to all persons. Likewise, a garage is assigned to those journeys that start in Munich. Similarly, a garage is also added to those trips at the beginning of the trips that start in Munich. This covers all possible cases and ensures that all on-street parking spaces except for short-term parking spaces are no longer parked in.

Parking Free City Centre

For the last scenario, it is assumed that no more vehicles are parked within the dense centre of Munich and that 100 percent of the parking trips are eliminated. Likewise, all trips with origin and destination within this inner city area are eliminated. These plans are therefore removed from the population (the plans file) in a first step. The inner city area of this model includes the following districts completely:

Districts within the defined city centre area
Altstadt - Lehel
Ludwigsvorstadt – Isarvorstadt
Maxvorstadt
Schwabing West
Au – Haidhausen
Sendling
Schwanthalerhöhe

Figure 14 City districts considered for the inner city area

The implementation of this model is analogous to the previous procedure, but with some additional conditions. As an example, the following figure shows what a plan looks like for a person who has previously travelled to the city centre and then back again. The journey begins for the person as usual with the car at their own home and then ends, however, not at the workplace, but at a “Park & Ride” (P&R) point where the person has to change to public transport to get to the city centre area. The vehicle parks in the “Park & Ride” car park until the person returns from the city. From here, the second leg of the journey home begins again with the person's own car.

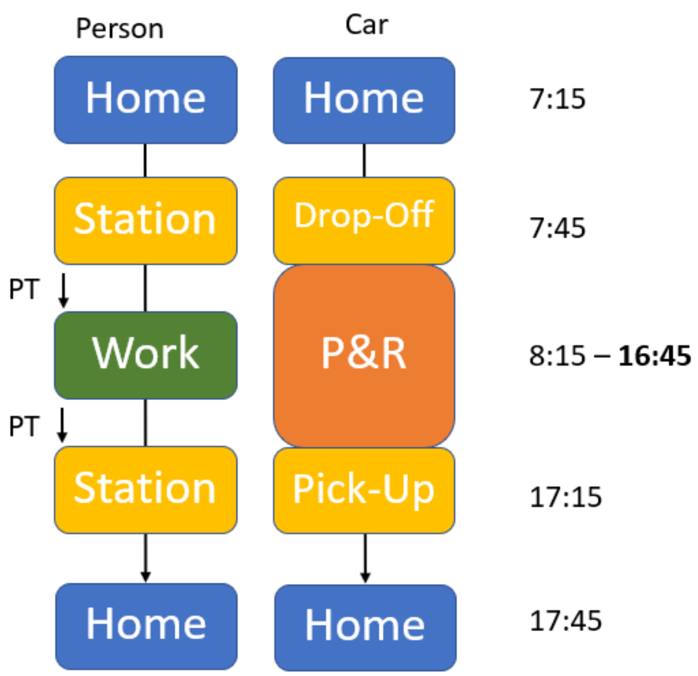


Figure 15 Implementing a park & ride garage

As with the other plans, this plan can be written along legs. There are therefore two possible approaches. One approach is based on the actual journey of the person. Following the exemplary representation, another activity "station" is added to the plan during the outward and return journey. One part of the original route is still covered by the "mode" car. The second part is covered in a new "leg" with the "mode" public transport. This variant serves to change the original plan little, to keep the type of activity in the inner city area and at the same time to be able to take into account the increase in the utilisation of public transport in the model. However, a focus of this work is on the dimensioning of alternative parking and therefore the focus of the plan is on car activity.

A new activity “Drop-Off” is therefore written, with a stay time of 60 seconds. The car then embarks on an imaginary journey to the garage, with the activity only ending when the person returns to the “Park & Ride” station. To do this, the Euclidean distance between the location in the city centre and the “Park & Ride” station is calculated and divided by an average speed of 30 km/h. This time is used as the journey time for the car. This time is assumed to be the travel time for the person using public transport and is added to the end time of the city centre activity. In the exemplary representation here, half an hour is calculated between the end of work and the arrival at the car. With this model, which creates the new plan along the activities of the car, it is also easier to determine how long and how busy the “Park & Ride” parking garage is.

For this model, many different cases have to be considered. Trips have relations to the inner city area (hereafter referred to as "centre"), to the rest of the city of Munich (which does not include the centre) and to the metropolitan region of Munich (hereafter referred to as "region"). The following table shows which conditions must be distinguished. Plans with journeys that have their start and destination exclusively in the region or in the centre have already been removed. The condition query during programming follows the pattern that first all relations are queried that contain the relation to "centre", i.e. one of the activities of the plan lies within the city centre area. This is important because the “shape map centre" is also contained in the “shape map Munich”. This means that if Munich were to be queried first and the activity was located in the "centre", there would be two possible cases.

Table 6 Scheme of the P&R- scenario for 30 percent of the population

Origin			**Destination**			**Return**
~~Centre~~			~~Centre~~			~~Centre~~
Centre	P&R	Munich DO	Munich (G / S)	Munich PU	P&R	Centre
Centre	P&R		Region		P&R	Centre
Garage	Munich PU	P&R	Centre	P&R	Munich DO	Garage
Garage	Munich PU	Munich DO	Munich (G / S)	Munich PU	Munich DO	Garage
Garage	Munich PU		Region		Munich DO	Garage
Region		P&R	Centre	P&R		Region
Region		Munich DO	Munich (G / S)	Munich PU		Region
~~Region~~			~~Region~~			~~Region~~

Table 7 Scheme of the P&R- scenario for 70 percent of the population

Origin			Destination			Return
~~Centre~~			~~Centre~~			~~Centre~~
Centre	P&R	Munich DO	Munich (G / S)	Munich PU	P&R	Centre
Centre	P&R		Region		P&R	Centre
Munich		P&R	Centre	P&R		Munich
Munich			Munich			Munich
Munich			Region			Munich
Region		P&R	Centre	P&R		Region
Region			Munich			Region
~~Region~~			~~Region~~			~~Region~~

As shown in the previous tables, all journeys start at a starting point "origin" and travel at least to a first "destination", where the journeys that have not entered a second "leg" and a third activity "return" end. Therefore, the right part of the table is greyed out. It is used when the plan includes a return journey. In principle, the structure can be seen as mirrored. Journeys that start in the city centre leave by car from the park and ride garage and end (in an exemplary plan) at a park and ride garage. Journeys that start in Munich either start (as in the 30 percent population) at their home (referred to here as a pick-up point (PU)) and end at a drop-off (DO) point. The vehicle drives the route in the run-up and in the run-down as an empty run. The patterns for the journey to the city centre also work in the same way. The journey with the car ends at a park & ride garage and begins again there with a "return" journey.

For the 70 percent population, the garage allocation only applies when entering the city centre. This remains free of parked vehicles.

5.5.4. Modelling Results

Allocation of the Plans

The following figures always refer to the five percent population. Consequently, the total number of the population is 74,201.

The allocation of the plans for scenarios 1-3 shows that the majority of the trips take place within Munich. As set in the scenarios, 30 percent of the plans are allocated to garages, while 70 percent are not allocated to garages. The following figure shows the distribution of the case distinctions. Of the 30 percent of people who are allocated a garage and have a residence in Munich (coming from the region or from Munich), the breakdown is as follows: 55 percent of the people stay in Munich for less than 2 hours and are consequently not sent to the garage. Whereas 45 percent are sent to a garage for a stopover of several hours.

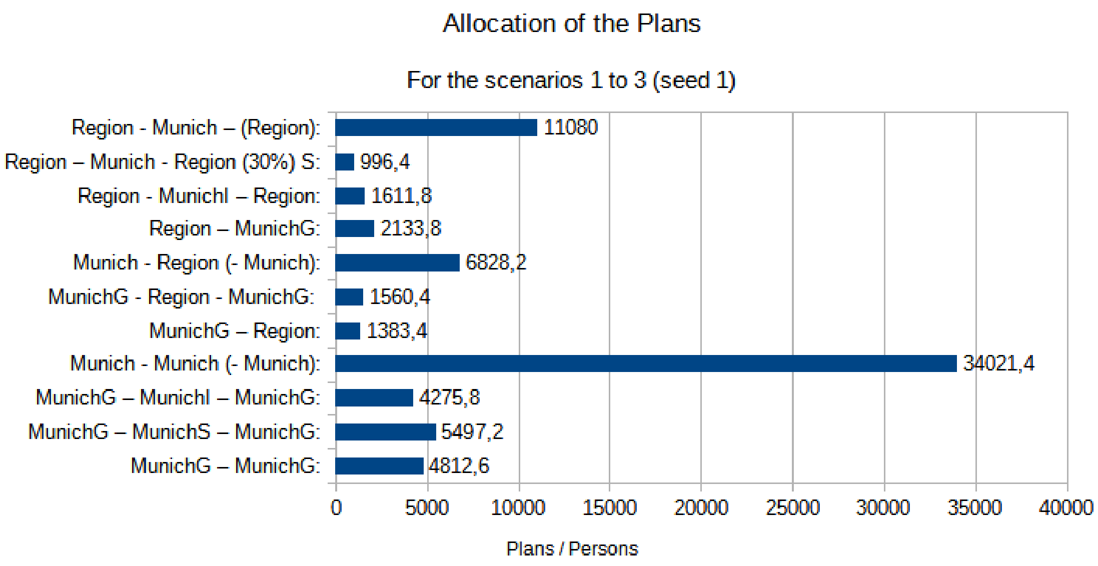


Figure 16 Allocation of the plans (Scenario 1-3)

The figure shows these intermediate stays either with "MunichI" representing the stay in the intermediate garage and with "MunichS" indicating the case of short-term parking. The cases in which 30 percent of the population is assigned a garage are represented by "MunichG". Furthermore, the 70 percent does not take into account whether the person also has a return trip in the plan (hence the representation in brackets).

This ratio, which expresses the length of stay of people who have a stopover within Munich, can consequently be assumed for the entire population, i.e. for the other 70 percent as well. The results are the same for all three scenarios and for several "random - seeds". This means that the location of the garage has no influence on the allocation to short-term parking or to an intermediate garage.

For the "park & ride" scenario, the focus of the evaluation is on the relationships with the inner city area ("Centre"). Trips with origin and destination within the centre no longer take place. That is 3129 persons. Even if this proportion of people no longer make journeys in Munich, it is only around seven percent of the total number of journeys within the whole of Munich, which is 43794. The share of people with either origin or destination in the city centre area amounts to 31 percent of the total population. For them, the journeys end and/or begin at a park & ride station. The illustration of this scenario is therefore different, as here a distinction is made between more cases in order to allocate the plans more precisely.

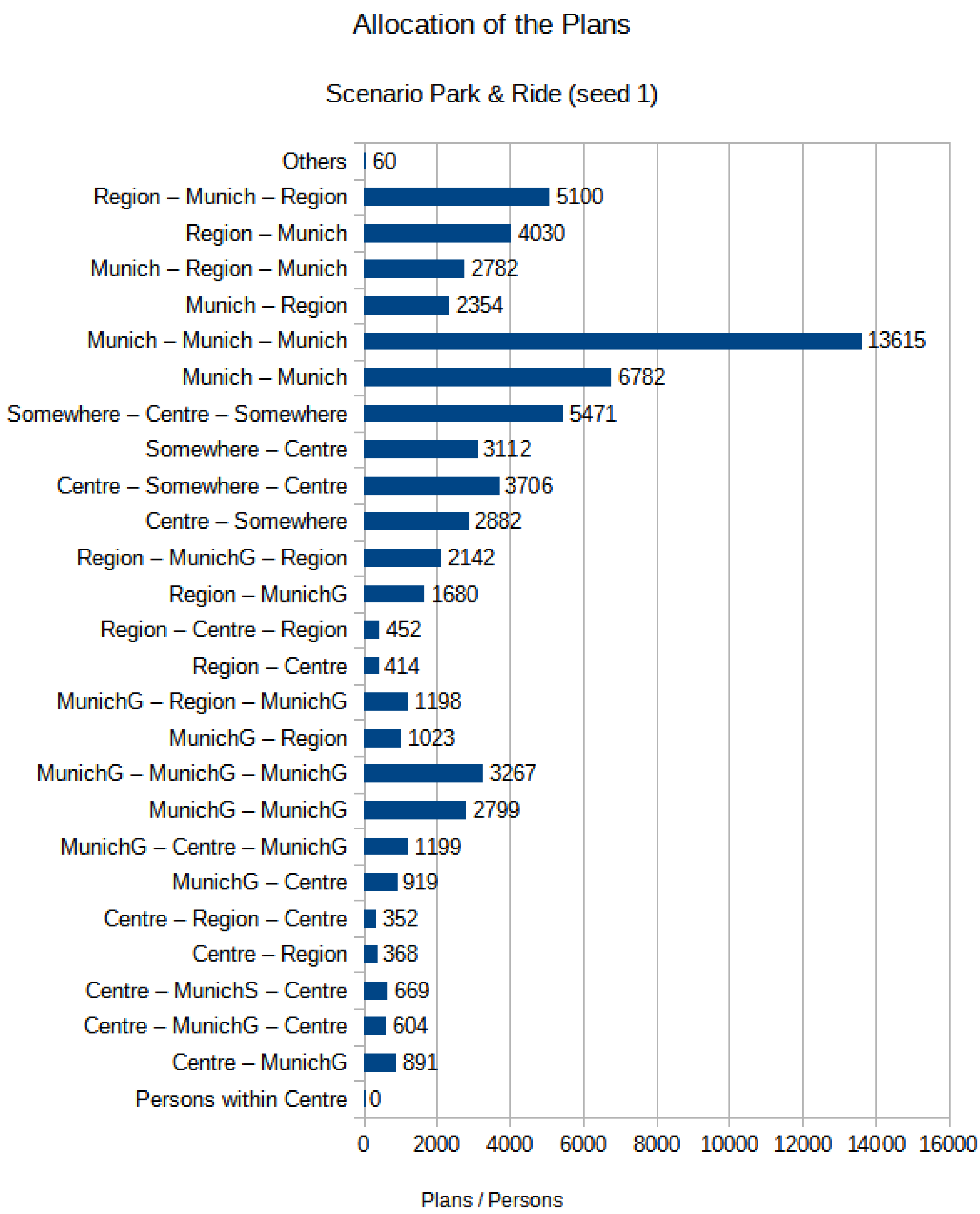


Figure 17 Allocation of the plans (Scenario P&R)

In the figure, all journeys that start or end at a park & ride station are still listed as "Centre". The designation "MunichG" again indicates to which 30 percent share of the trips that are within Munich but outside the city centre area a garage is assigned. For journeys of the 70 percent share to which no garages are assigned, no distinction is made for this evaluation between the location of the destination in Munich or in the region.

Event Analysis

The evaluation of the congestion analysis (see figure 18) shows that congestion in Munich has increased significantly in all scenarios with garages compared to the *state-of-the-art* scenario. While an average journey (referred to here as a person) in the *state-of-the art* scenario is delayed by just under half a minute or is stuck in a traffic congestion, a vehicle in the scenarios with garages is stuck in a traffic congestion for over an hour on average. In the scenario with two garages, the journey takes around 1.5 hours less than if all parking journeys were concentrated in one garage. In contrast, journeys in the scenario with 24 garages are delayed by around 0.4 hours compared to the scenario with only one garage. If, however, the inner city area is free of parking trips as in the *Park & Ride* scenario, but the number of garages remains at 24, the delay is reduced by around 2.5 minutes per person or trip.

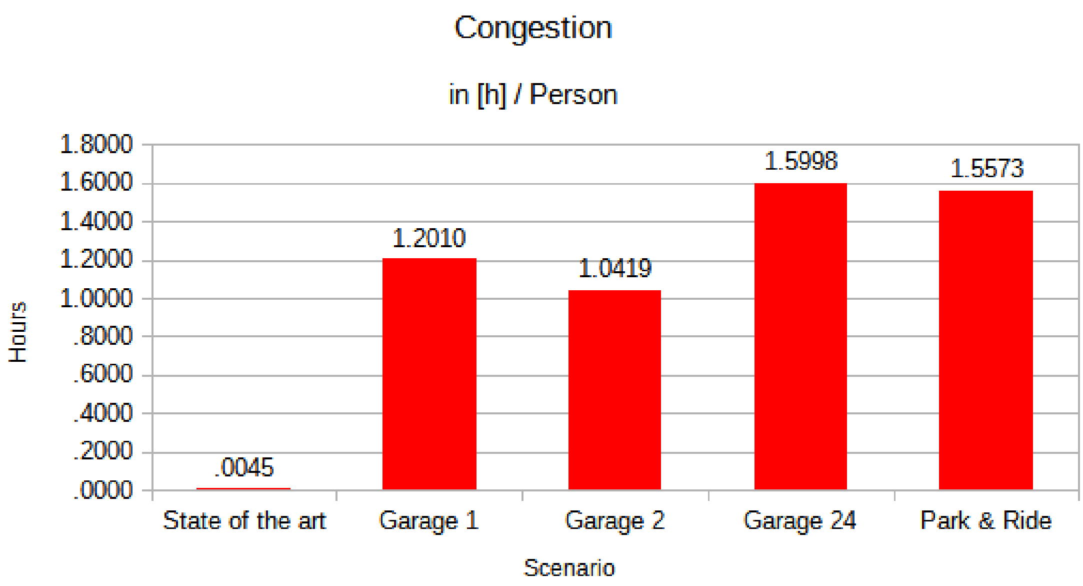


Figure 18 Comparison of congestion times

Garage Trip Duration and Distance

Examining the total travel time of the garage trips to the collective garages in the four scenarios with collective garages, a clear trend can be identified (see figure 19). The more garages or garage locations are available, the shorter the garage trips are on average. In the last scenario, in which no parking trips take place in the inner city area, the travel time from the garage to the pick-up location is reduced by another 20 minutes, while the travel time to the garage increases slightly for the first time. Considering all four scenarios, the trips from the garage to the pick-up location take on average between 8.3 and 2.12 hours, while the respective trips back to the garage take on average only about half as long per scenario.

Note: In order to make the scenarios comparable with each other, the same *seed* was used for randomisation in the evaluation.

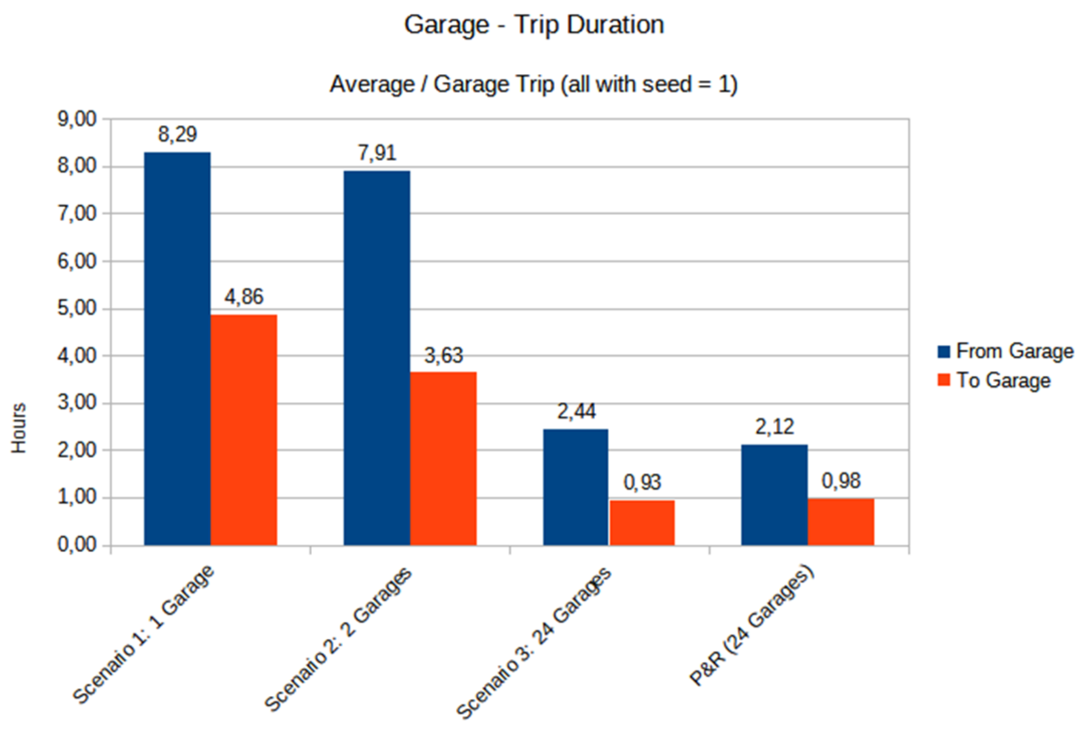


Figure 19 Garage trip duration

A trend can also be seen when examining the average trip distances (see figure 20). Here it becomes evident that the more garage locations a scenario offers, the shorter the trip distances. Compared to the scenario with only one garage, the trip distance with 24 garages is only about a quarter or a third. In the last park & ride scenario, the distances increase again by 0.34 or 1.37 km compared to the scenario with 24 garages but without city centre restrictions.

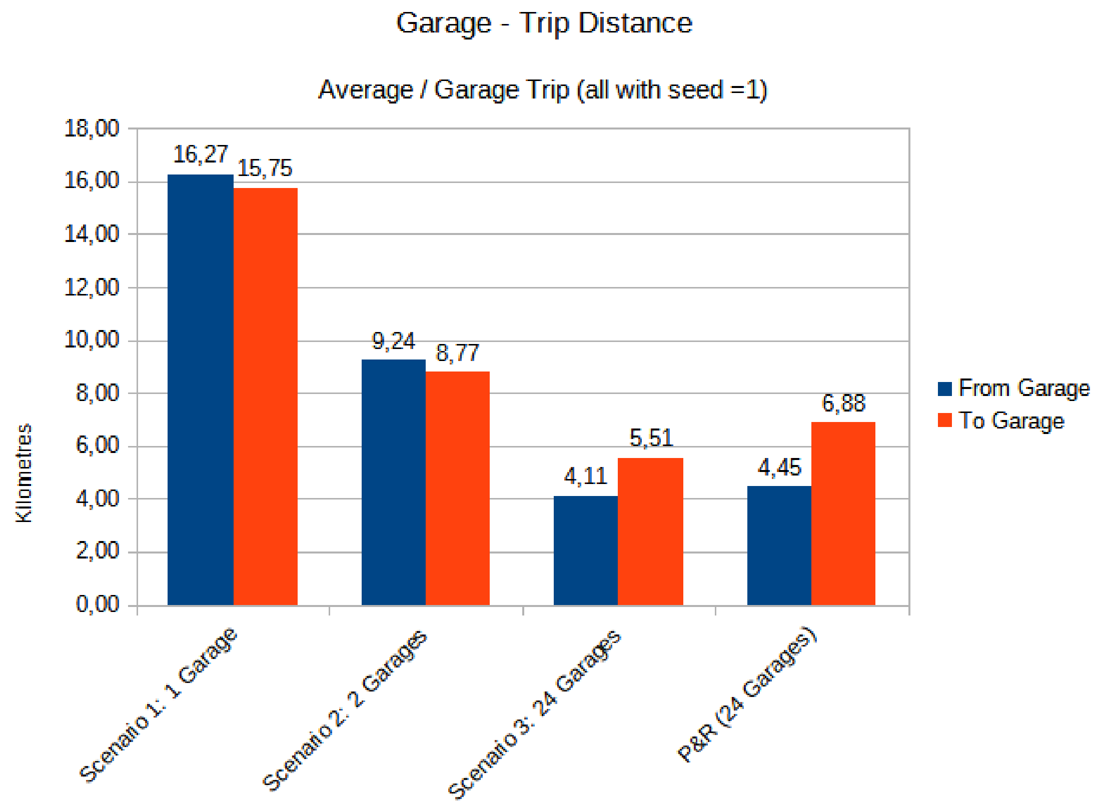


Figure 20 Garage trip distance

Trips Counted

In order to better interpret the numerical results presented so far, it is necessary to examine how many trips per scenario could actually be simulated. It turns out that the more garages a scenario has, the more trips could be made (see figure 21). Almost 13,000 trips in the scenario with 24 garages from the garage to the pick-up location are compared to almost 1,250 trips in the scenario with only one garage. Comparing the two scenarios with 24 garages shows that fewer trips could be made in the scenario with a parking-free inner city area and *Park & Ride* garages. The difference is roughly equivalent to the number of trips that were forced to make a modal shift in this scenario, as both the source and destination of the trip were within the city centre. For all scenarios, fewer trips were made to the garage than in the opposite direction.

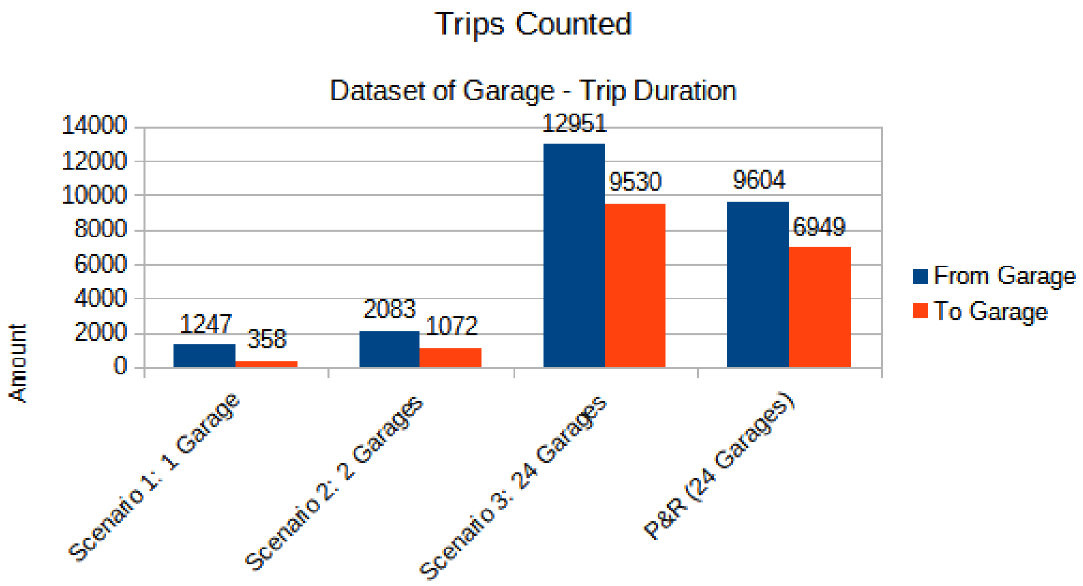


Figure 21 Counted garage trips

6. Future Concepts

6.1. Scenarios for Munich

The Easyride project is the largest project to date of the City of Munich on the topic of autonomous driving. As can be read on the project's website, the project serves to prepare the city administration for the possible effects of automated driving on mobility and traffic in order to be able to shape these for the benefit of the citizens (Easyride, n.d.). It also states that the project participants use four scenarios to describe the mobility and traffic situation:

- Unregulated individualism (1)
- Mobility offers without limits (2)
- A new world of mobility (3)
- Individual mobility 2.0 (4)

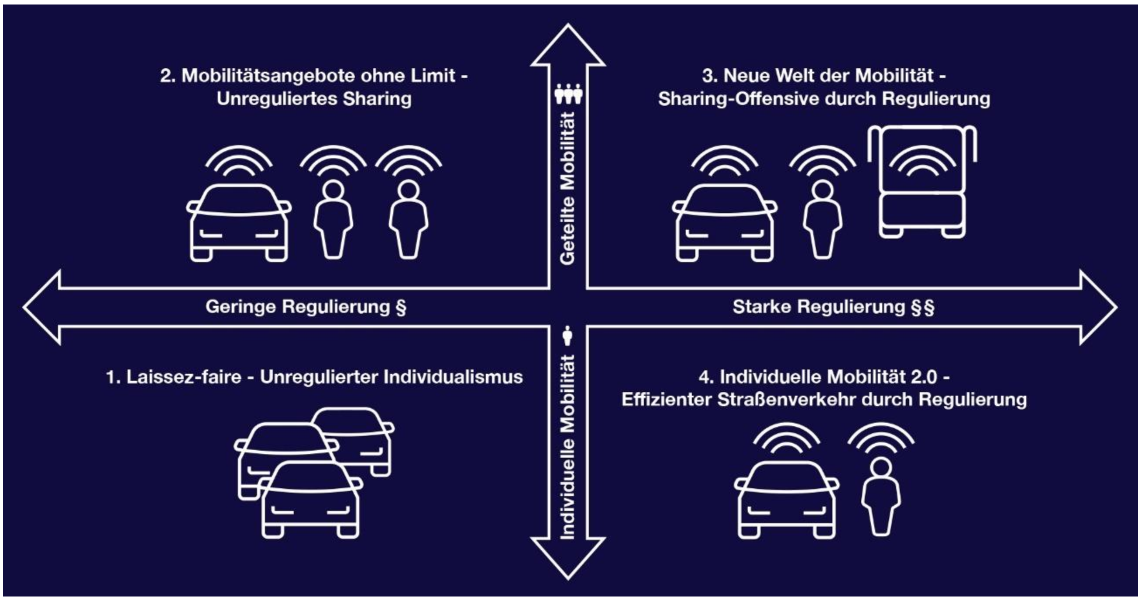


Figure 22 Scenarios for 2030, Source: (Easyride, n.d.a)

For all four scenarios, on-demand mobility services are assumed, which sometimes influence the modal share to a greater or lesser extent. Depending on the penetration of these services in Munich, the project team assumes a change in vehicle sizes. If the vehicles are shared more often (ridepooling), larger vehicles are to be expected, while in the case of individual use (private ownership, ridehailing or simple ride-sharing) the typical vehicle sizes do not (have to) grow. So far, no results of the pilots associated with the project could be published.

Schütte (2021) locates the use of autonomous technology spreading outside cities on motorways first. He states that the technology is currently expensive and it is very difficult to programme vehicles for everyday situations in residential areas where many disruptive factors can influence traffic.

With regard to autonomous parking, Schütte (2021) points out that the question of liability during a journey is an unsettled area, especially in the case of empty journeys without passengers. He states that it can be assumed that it is difficult to assign liability to the owner of the car during this drive, while car manufacturers are generally looking for ways to exempt themselves from liability. This is only one of many unresolved issues. Schütte (2021) considers a restriction of traffic volume necessary in view of the expected population growth of Munich and the surrounding area.

Another point is the early inclusion of parking infrastructure in future scenarios. The conversion of classic parking spaces into drop-off / pick-up areas should be street-specific and this requires mobility planning that goes beyond individual streets. If several entrances or exits take place in close temporal and geographical proximity to each other, congestion effects can occur (Chai et al., 2020, p. 27). It should therefore be examined whether such areas in the side streets of busy roads have a negative influence on traffic flow.

6.1.1. Toll System

Sieg (2018) awaits that driving for autonomous vehicles will be cheaper than parking and therefore road pricing will become inevitable. Sieg (2020) also supposes that a toll system is already a suitable means for the city to distribute traffic load more evenly and thus increase welfare gains. At the same time, a city toll can lead to an overall shift of 10 percent of motorised private transport to public transport and shared mobility - at least if public transport is already well developed (Sieg, 2020). The toll is also a contribution to better reflecting the true costs of individual motorised transport (Stadelmann, 2018).

Schütte (2021) determines advantages above all in a static dynamic toll. A dynamic system has the advantage that the amount of the toll can be dynamically adjusted to actual events. If the amount of the toll is increased during traffic peaks, this can be an incentive for drivers to switch to a different time period and thus the utilisation of traffic becomes more even over the entire duration. At the same time, Schütte assumes it is important to give citizens an orientation and therefore to make the tariff model static and comprehensible. He explains that, for example, the same tariff applies every morning during rush hour, while it is lowered again during the course of the day when rush hour is over.

6.1.2. Strengthening the Environmental Alliance

The Munich municipality is already using different concepts to manage traffic in Munich. Schütte (2021) emphasises that public transport has priority in the transport system and mobility concepts should support public transport. Part of this strategy is that the city wants to keep car density low in new developments and new neighbourhoods from the beginning. Klug (2020) emphasises that creating housing is a higher priority than creating sufficient parking space. He explains that it is only possible to deviate from the parking space statute if these spaces are owned by the city and thus allocation criteria can be defined, such as ecology and mobility. He goes on to say that the developer is subsequently also subject to a reporting obligation on how the vehicle stock is developing and whether the criteria are being met. As examples, Klug (2020) cites the development of the Bayernkaserne Schwabing and the development of the new district in Freiham. The vehicles, which are reduced in number, are housed in collective garages at the edge of the neighbourhood (so-called "Quartiersgaragen"). Klug (2020) explains that this both avoids parking trips through the neighbourhood and limits the accessibility of the car somewhat, so that the distance to other means of mobility can be shorter and the incentive to use them higher.

Schütte (2021) states that motorised private transport should be kept out of the urban area as much as possible and therefore no park and ride car parks should be built within the *Mittlere Ring*. At the same time, he also refers to the current bottlenecks of public transport in the city centre, whose cross-sections do not allow for a significant increase in passenger traffic volume during peak hours. Schütte (2021) therefore also determines a need to strengthen the bicycle infrastructure with, for example, a bicycle ring. Klug (2020) refers to the bicycle parking statute, which guarantees a minimum number of parking spaces per flat.

6.2. Conversion of Transportation Infrastructure

At the end of this chapter, the question remains as to the potential for re-use of freed-up or released traffic infrastructure of motorised individual transport. Both for the scenario with autonomous vehicles in private ownership and for a scenario with shared vehicles, at least pick-up / drop-off areas are necessary. Nevertheless, the results so far have shown that the on-street spaces in particular can be used for other purposes. They can continue to serve as traffic infrastructure and be added to the cycling infrastructure. Either in the form of cycle lanes or parking areas. But greening or use as living and working space, as well as recreational areas are also conceivable, as the following subchapters shows.

6.2.1. Munich

In Munich, too, there are already concepts for using areas that were previously used for transport infrastructure for other purposes. One project is called "Summer Streets Munich", for which a total of 14 streets were temporarily converted into traffic-calmed areas or play streets over the summer of 2020. Car traffic was deprived of lanes and parking spaces or vehicles had to drive at walking speed and pedestrians had priority. In addition, planters and benches were placed for people to rest (Landeshauptstadt München, n.d.-a). Another pilot project was the so-called "pop-up lanes", where temporary bicycle lanes were installed on car lanes. However, they had to be dismantled again and it remains to be seen whether and how they can return (Klug, 2020).

The architectural office "studioeuropa" is pursuing a completely unique approach with its "additional space", which has the size of a vehicle and can be parked at car parking spaces. According to the creators, this means that very cheap space can be offered in "prime locations" at very low cost, as only the fee for a resident's parking permit is due for the use of these spaces (30 euros / year) (studioeuropa, n.d.).

6.2.2. View to Other Cities

Pontevedra is a city in north-western Spain with a population of around 83,000 (Wikipedia, 2021). As the Sachverständigenrat für Umweltfragen (2016, p. 356) points out, in the 1990s the city's streets and squares were unattractive and over-parked and city centre life was not thriving. It was not uncommon for parking searches to take 15 minutes (Urban, 2018).

The city council decided to counteract this development and developed a concept to make the city centre as car-free as possible. As the Sachverständigenrat für Umweltfragen (2016, p. 356) states, active mobility (walking and cycling) was prioritised in the old town and space for pedestrian traffic was reallocated. It goes on to say that the changes were gradually extended to the entire city area, and in return many free park and walk spaces were created in the outer city rings, from which the city centre is easily accessible. As a result, the traffic volume in the entire city was halved, which is also due to the fact that within 15 years (from 1999 to 2014) the daily car use was reduced from 52,000 to 17,000 vehicles (Sachverständigenrat für Umweltfragen, 2016, p. 356).

Contrary to the fears of local businesses, there have been positive effects on the economy. Urban (2018) states that sales of city centre businesses have increased as streets and squares have become dwell zones. Urban further attests that the success is linked to the fact that visitors no longer have to adapt to time-consuming parking search traffic but can reach the city centre unhindered by environmental transport.

Since there are so few vehicles on the road in the city, there is no longer a separate infrastructure for car traffic and active mobility always has priority (Urban, 2018). And yet, or precisely because of this, there have been no more traffic fatalities in recent years that were previously caused by drivers, as Urban (2018) points out. He goes on to write that sports fields and playgrounds have been created on former car parks, many plantings have been made and the city has become much more attractive.

The Norwegian capital Oslo has also reduced parking space in favour of a more sustainable and healthier city. Through the programme "The Car-free Livability Programe", 760 parking spaces in the city centre were reduced or redesigned and the spaces were handed over to the population for changed use (Oslo Kommune, 2019, p. 11).

There are many after-use opportunities and as the examples of these two cities show, such concepts can be very successful (see also figure 21).

Figure 23 Conversion of parking spaces, Source: (Oslo Kommune, 2019, p. 26)

7. Discussion of the Results

7.1. Area Analysis

Overall, a large number of areas were found that have the potential to be converted into parking spaces. The potentials can be scaled by dividing them into types. Thus, among the potentially eligible track areas, only the areas that best meet the previously defined criteria were selected. Under certain circumstances, after the criteria have been adjusted, some areas can be omitted, but also the current ones can be supplemented. Here, effects in the order of doubling the areas to around 3.5 km² are possible. Economies of scale up to a multiplication are also possible in the selection of commercial properties. With the detected areas, which are about 3 km² in total, it is shown that already sealed areas, which are still in demand and used at these locations, can cover the parking space requirements of all on-street parked vehicles. It could also be shown that by layering the parking areas, all vehicles registered in Munich can be accommodated in these collective garages. Constructional and also legal questions of implementation have been taken into account in the preparation of the criteria, but not completely and only qualitatively assessed.

The manual recording by means of the evaluation of the aerial photographs does not allow for a square metre exact recording of all areas. For this reason, the areas were drawn somewhat smaller in length or width than the aerial photograph would allow. Furthermore, an uncertainty factor of up to 10 percent was taken into account in the calculation of the areas, which is subtracted from the recorded area sizes of the individual areas in order to obtain a rounded value. It cannot always be completely ruled out whether existing parking areas in all recorded cases are purely car parking areas or whether individual areas are intended for trucks or, for example, heavy goods vehicles. Many small or potential parking areas were not taken into account. This is not only because the realisation of parking facilities on small areas is less profitable, but also to compensate for any remaining uncertainties in the determination of the respective total area potential per type. It should also be taken into account that the aerial photo evaluation shows a photograph taken on one day and during the day. Neither the day of the week nor the time of day is known. In some cases, it is only possible to guess how high the parking space utilisation actually is at this location and what other uses some of the identified spaces have.

It has been shown that automatic parking systems can accommodate a large number of vehicles in a very small area. This supports the assumption from the literature that these systems are more efficient than conventional ones. It was also possible to determine a factor with which the maximum possible vehicle capacity can be determined for both small and large areas.

The overall result of the area analysis is within the expected range and support the research hypothesis that sufficient spaces can be found to replace on-street parking.

7.2. Modelling

A way could be found to map the additional garage trips in the existing plans and to design and simulate different scenarios from these combined plans. However, this combined approach has small weaknesses, as the duration of some trips must already be known when the plans are created and they must therefore be estimated, which distorts the model somewhat. In addition, assumptions had to be made as to what percentage of the population should realistically switch to collective garages. By dividing the population into a share of 30 percent and a share of 70 percent, it was possible to roughly represent the ratios that the literature and experts see for the division into on-street and off-street parking in Munich. It is therefore also realistic that the on-street share (the 30 percent) are consequently sent to the collective garage, while the 70 percent share of the population continues to park off-street at the "usual" place. The evaluation of the allocation into individual groups that fulfil the respective "if-conditions" worked. The allocation is realistic, which shows that the programme code classes are written correctly (at least in this respect).

The plans were created with the help of "random seed". And the mean value was calculated. The consideration has only marginal effects. Similarly, 30 iterations were run for each of the scenarios 1 and 2, whereas 50 iterations were run for the scenarios with 24 garages. However, the approximation showed that the results are already in the plausible range. It can be assumed that the simplifications have not had a major impact. For example, it can be assumed that through traffic (starting point and destination outside Munich) does not pass through the inner city streets and can therefore be neglected for the simulation, as the trips do not affect inner city traffic.

The evaluation of the congestion hours per average trip and scenario shows that the garage trips have a great influence on the average trip duration. On the one hand, this is due to the fact that the garage trips themselves take a very long time and thus alone increase the statistical average value. On the other hand, it cannot be ruled out that some tailbacks in front of garages also have an impact on the passing traffic and that uninvolved trips get caught in this congestion. Although a second garage at the other end of the city reduces the average congestion time, the time increases when 24 garages are available. The first effect can be attributed to the fact that the garage trips are split in two cardinal directions and between two garages, thus utilising the road and garage infrastructure more evenly. The second statistical effect can be explained by the fact that some of the 24 garages are located in places where the road infrastructure is congested much faster than the infrastructure of the first two garages. At the same time, the scenarios with 24 garages simulate several more trips than the first two scenarios. From this it can be concluded that the throughput of entries and exits from garages must be many times higher the more garages a scenario has. This in turn means more (delayed) trips that are included in the congestion statistics and thus increase the total congestion hours.

The evaluation of the garage trips shows that a higher density of collective garages or their more homogeneous distribution in the city has a positive effect on the distances and also trip durations of the garage trips. The evaluation of the scenario with an inner-city area without stationary traffic does not give a clear, because contradictory picture. It could be assumed that the traffic flow in the park-and-ride scenario would improve simply because 3,129 fewer people travel by car. This positive effect is particularly not evident for the trip distance results. The significantly shorter travel times of the trips to the garage lead to the assumption that these trips (usually return trips) accumulate less at the bottlenecks at the garage entrances and exits, as they can be spread out over the remaining (simulated) day. Whereas many of the trips starting at the garage tend to start earlier in the day as they are the first trip of a schedule in most plans.

The bottleneck of the entire simulation analysis is the throughput of entries and exits at the garages themselves. In individual trip evaluations, it could be determined that trip plans that take place almost according to plan in the state-of-the-art scenario sometimes do not even reach the road network in the scenarios with few garages. In the scenarios with 24 garages, most of the plans used for the individual evaluation could be simulated completely. This means that a significant proportion of the planned parking trips do not take place or do not reach their destination within a simulated day. The latter explains the significantly lower number of trips to the garage in each case. These results are confirmed by a separate evaluation of the journey times per grouped individual journey (see appendix III – trip durations pattern). This shows that trip durations of over 60 min occur particularly frequently for garage trips. As a result, the intended recording of the effect of the parking trips on the remaining traffic cannot be determined more precisely in the overall evaluation of the scenarios. The throughput can be increased for this simulation on the one hand by designing the road infrastructure in front of the garage for a higher capacity (similar to a system in front of a large stadium). For this, the road network on which the simulation is based would also have to be adjusted. On the other hand, a better distribution of parking spaces to more and more collective garages (distributed as homogeneously as possible across the city) leads to a better throughput of parking trips. Only when all planned parking trips can be simulated within a day the effect of parking trips on other traffic can be determined more precisely. It can be assumed that the more collective garages are offered, the better the parking traffic can be distributed, and its trip distances and duration reduced.

7.3. Ecological Effects

Ecological effects can be assumed both for the comparison of current parking areas with potential parking areas and for the comparison of traffic patterns. The extent to which the different types of spaces are suitable from an ecological point of view was assessed. Further studies are nevertheless necessary in order to be able to speak with final certainty. The result that no more land needs to be sealed and that, on the contrary, land can be made available is an ecological plus. The possibilities for electric charging offered by collective garages should not be underestimated. If battery-powered electric driving becomes established, on-street parked vehicle owners in particular will be con-fronted with the problem of finding charging spaces. Several problems arise here: charging connection, charging management and ensuring safety during charging.

By double-using ("shared parking") the infrastructure of customer or employee parking spaces, the need for charging infrastructure can be halved. In collective garages, the batteries of the entire fleet of parked vehicles can be optimally charged with intelligent charging management. It is also conceivable to use the batteries of the vehicles as buffer storage to compensate for grid fluctuations. Solar panels on the car park building can feed the electricity directly into the batteries of the vehicles without intermediate storage and over a short distance - without significant losses (Engel et al., n.d.). These points can be taken into account especially with a central parking infrastructure.

This is contrasted with the additional kilometres and its ecological consequences that a vehicle drives to the garage and back again if the drop-off points continue to be close to the destination. With the help of modelling, it could be shown that the change in traffic patterns is significantly affected, at least locally around the garages. How this affects the wider network requires further research. With the "park & ride" scenario, it could be shown that the total congestion time is significantly reduced, indicating a reduced traffic volume in the city centre area.

7.4. Future Concepts

The results from the chapter "Future Concepts" show that the city administration is already playing through different scenarios of an autonomous future and otherwise focuses on reducing motorised individual traffic today. This is not surprising, as Munich, like many cities in Germany and the world, is struggling with increasing motorisation (compare Study Area: Problem Description). With its concept of neighbourhood garages in new urban districts, Munich is relying on a "small version" of the conceptualisation of this work. Whether this will have the desired effects of reducing the number of vehicles and encouraging a switch to public transport remains to be seen. Comparable concepts from other cities were also not part of the investigation of this work. However, it could be shown that, based on the example of Oslo and especially Pontevedra, the conversion of parking and traffic areas in general can be very profitable for the livability of a city. Therefore, it can be right for a city administration to limit motorised private transport in time with different instruments ("pull" and especially "push" factors), as they were also touched upon in this thesis.

Overall, the research hypothesis could be confirmed. There is sufficient space to replace on-street parking and there are also many reasons for this, but also against it. The main arguments in favour are the increasing pressure on space in city centres and the many requirements such as the creation of green spaces due to climatological and biological concerns. Against this, if the pattern of individual, motorised mobility remains the same, are the additional parking trips. However, these could be eliminated if the journey by car always ends at the edge of an inner city area and the remaining route can be covered with the environmental network or also new mobility concepts. This was not only the approach of scenario 4 (park and ride) but is also shown by the example of Pontevedra.

8. Conclusion

8.1. Reflection

Today, moving traffic and stationary traffic are necessarily interconnected. Even if there is no significant increase in mobility behaviour and the share of public transport in the modal share is growing, the number of vehicle registrations is rising and with it the amount of parking space required. Not only this trend, but also the increasing urbanisation and densification of settlement areas lead to increasing competition for space. Not only this trend, but also the increasing urbanisation and densification of settlement areas are leading to increasing competition for land. This is despite the fact that climate change and the loss of species make it necessary to preserve and expand natural areas.

Following this problem, the effects of autonomous parking on land use and traffic had to be examined. The objective of this work was to reclaim the street side spaces for other purposes than parking, while at the same time adequately accommodating all vehicles parked there so far. For this purpose, the number of on-street parked vehicles was estimated and sufficient alternative spaces of different types were found at different locations in Munich. Experts were recruited to assess the feasibility of the overall objective. Not every area and not every type of area could be examined and assessed in detail by experts. One expert could be won for the technical feasibility of large automatic parking systems. The idea of the work could be discussed with municipal urban and mobility planners and compared with their strategy.

The second part of the study concerned the analysis of the effects of the additional parking traffic on the overall traffic situation if all on-street parked vehicles could be accommodated in collective garages. The aim was to find out how many additional kilometres would be driven and how congestion would change. For this purpose, different scenarios were designed, with one, with two and with approximately one collective garage per district. The overall effects of the different scenarios were to be compared with each other. The idea seemed simple, the amount of work is considerable and was underestimated.

Overall, it has been shown that Munich has no shortage of alternative parking areas, whose surface area is already sealed and most of which are also well connected to the existing transport infrastructure. Railway tracks within Munich have proved to be particularly suitable and easy to build over. Especially convincing were the advantages of only having to work out this concept with one owner and, in most cases, being in the direct surroundings of public transport stops. This also makes it conceivable to implement this concept even before the implementation of autonomous transport and to integrate it into a mobility concept that aims to reduce motorised individual transport in the inner areas of Munich.

8.2. Limitations

This work follows several new approaches. While banning traffic from inner cities is already being applied, there are no large test fields in cities yet for autonomous driving, especially on the topic of autonomous driving and parking in large collective garages. The dimensioning of automated collective garages on this scale has also not yet taken place.

Limitations resulted in part from the fact that not all discussion contents from the expert interviews were released by the experts. This is almost predominantly due to the fact that the results of new projects, for example, have not yet been published in their final form and may still be subject to change. But there is also the reason that some experts could only give their private opinion on some topics and there is a risk that this could be misunderstood with the official position of the company. It was also not possible to reach all the experts contacted, and in some cases the confirmation came after the chapter on this topic had already been written. Therefore, not all results could be included.

The investigation of the different types of areas has its limits, because two areas of the same type can be very different. Nevertheless, a way had to be found to categorise the study. Also, the assessment of the suitability of each identified area could only be done superficially and selectively within the framework of this work. Of course, the assessment of the owners of all these areas could not be taken into account. Even though at least some were contacted and assessments could also be obtained from responsible experts, especially for the track areas. The potential of the already existing off-street parking areas could also only be partially recorded, as no bundled and openly accessible data sets could be found. In addition, the concept of "shared parking" is not yet widespread in Munich. The areas of the identified car parks and a large part of the customer and employee parking areas could at least be considered for this in the future.

The dimensioning of the automatic collective garages was only based on a few framework data. Although an expert was recruited who could give a rough estimate, it was not possible to carry out more in-depth static, legal, technical and other checks. The conceptualisation remains at a ideal level.

The results of the simulation - even if they are quantitative - are to be understood as a rough direction, since on the one hand the model itself is only a "model" and on the other hand the adaptation and extension of the data sets is not fully differentiated. For instance, as the input data for the simulation is based on the MiD 2008, the traffic pattern may not correspond to the current one. The modal share was 3 percentage points higher than the share of the MiD 2017. In the same period, the number of inhabitants and the number of registrations also increased, which may have a compensating effect. Furthermore, within the time frame of this work and taking into account the author's prior knowledge of modelling, no in-depth analysis could take place as to whether all data are plausible. The assessment was made by testing with two different, small test data sets, as well as by tracking individual trips in the overall data set when analysing the simulation results. Readers of this paper should take note. Further research is needed here.

8.3. Further Research

Further research is needed in various areas:

The developed simulation model can be further developed. This can be a further differentiation or just an adaptation of the generated plans to be able to depict other scenarios. In order to be able to make a precise statement about the impact of the garage trips of these scenarios (especially the P&R concept) on the general traffic, the obstacle of the bottleneck at garage entrances and exits must be removed. This can be tackled with different approaches. For example, the number of garages can be increased, the garages can be distributed differently (away from roads that are already congested), the allocation of vehicles to garages can be optimised to achieve a more even distribution of entries and exits over time.

Other scenarios could be a Munich with fewer or more vehicles, or a differently defined car-free or car-reduced inner city area. Likewise, many other insights can be gained from the generated simulation results. For example, it can be researched in which radius and on which specific streets the influence of collective garages or parking trips has an impact on the traffic network. The evaluation methods can be made more precise and, if necessary, corrected to obtain more plausible results.

Another area is the more in-depth examination of the identified areas as being suitable for building over with parking spaces. Here, a wide variety of criteria need to be examined. For example, the investigation of the ecological function of the track areas requires the inclusion of the surrounding areas and an on-site investigation.

One more field is the investigation of Munich's transport network for the suitability of large collective garages. As the results of the simulation show, many vehicles cannot leave the collective garage because the surrounding road network is already at capacity. Here, it can also be investigated how this problem can be alleviated by possible minor adjustments to the network, such as connecting the collective garages to roads with greater capacity.

Likewise, it can be investigated how many transfer stations are optimally needed in order to distribute a large number of vehicles from the collective garages to the transport network in a short time. Further studies of collective garages in terms of statics, economic efficiency and technical feasibility can also be investigated.

Further research is needed in the area of "shared parking" to investigate how much space potential actually results in cities when residents' parking can be shifted to customer or employee parking areas. Further research is also needed on how this dual use can be technically organised and how it affects traffic.

What changes autonomous driving will have on infrastructure and traffic behaviour/traffic patterns requires further investigation. The four scenarios developed by Easyride are an initial orientation for traffic planning in Munich. Which and whether one of these scenarios will materialise is not only a question of technical development, but ultimately also of the political framework.

If the implementation of a collective garage concept (park and ride) in the sense of this paper is to take place in Munich before the introduction of fully automated transport, the crucial question is whether public transport at these locations can transport the occupants of the vehicles to and from the garage. It must be examined whether the existing infrastructure is sufficient or can be expanded to cope with the partially increasing traffic volume of public transport and around the garages.

This also raises the question of which transport policy instruments will persuade the population to accept a concept that is new on this scale. This also needs to be investigated.

8.4. Personal Assessment

Simulations are a very good method to study dispersion events and the effects of such dispersion events. They are crucial for the mapping of traffic flows and are able to show the effects of changing parameters such as a change in the network, the change in the number of vehicles per traffic route segment or changes in the modal share behaviour. Both the quality and quantity of the input data play a major role. For example, the effects of increasing parking pressure in an area can only be captured as accurately as the network data set resolves. With coarse resolution, side roads or the distribution of traffic on side roads, for example, cannot be recorded, which includes an uncertainty factor. If priority regulations are not stored, the results of the simulation can also be distorted, at least to the extent that the consideration of these regulations has effects on the route choice and thus also on the journey time and congestion.

The factor of topicality of the data set plays an even more important role, the faster the traffic conditions which are to be mapped change in the respective study area. For Munich, it could be assumed that the traffic situation has not changed significantly, despite the fact that the partial data sets are several years old, and that the results retain their validity. However, every user must be able to consider and assess this assessment before using these data sets.

In retrospect, the time required for the programming work could have been reduced many times over. On the one hand, of course, if the basics of programming in general and prior knowledge of *MATSim* had been available. On the other hand, through a coarser approach with which presumably similar results could have been achieved. As it turned out later, the path taken was much more laborious but also more consistent.

If the author of this thesis had to write again under the same conditions, he would programme the plans and scenarios in a less differentiated way in order to be able to go deeper into the analysis. He would also pay more attention to the opportunities created by "shared parking" and focus the expert interviews and research further on this topic. This concept seems to him to be both quick to implement and very effective. It is also the most resource-efficient solution presented in this paper.

It must be taken into account that this concept alone will not bring about a reduction in the vehicle population. Other instruments are needed for this. As far as a future with autonomous vehicles is concerned, the author of this paper is sceptical as to whether this technology will solve traffic problems and help to reduce vehicle density, or in sum create new problems. The all-round monitoring that is necessary for this technology requires a high level of technology in the vehicle itself, but also in the infrastructure and thus also in the cityscape, which entails a change in city life and the experience of the city. The possibility of parking the vehicle elsewhere and thus creating open spaces in core settlements is tempting but can also be achieved through a strong environmental network with complementary shuttles. The risk of public transport suffering from the introduction of autonomous driving, jeopardising basic services and low-barrier access for all citizens, must also be averted. The risk associated with this scenario must be discussed early and comprehensively.

9. Bibliography

(See also list of experts at the end of the bibliography)

Allianz-Arena. (n.d.). *Anreise & Parken*. Allianz Arena. https://allianz-arena.com/de/die-arena/anreise-und-parken

Association of the German Automotive Industry. (2017). *Automatisierung—Von Fahrerassistenzsystemen zum automatisierten Fahren* (p. 28). Association of the German Automotive Industry. https://www.vda.de/dam/vda/publications/2015/automatisierung.pdf

Baden-Württemberg, S. L. (2010). *Agrarstrukturen in Deutschland – Einheit in Vielfalt*. 73.

Becker, U. J. (2016). *Grundwissen Verkehrsökologie: Grundlagen, Handlungsfelder und Maßnahmen für die Verkehrswende*. oekom Verlag.

Berninger, S. (2019, July 19). Aldi, Lidl & Co.: Kunden ärgern sich über Parkplatz-Abzocke. *https://www.fr.de*. https://www.fr.de/wirtschaft/aldi-lidl-co-wegen-kostenfrei-parken-12442958.html

Brandes, D. (2015, October 27). *Die Flora auf (städtischen) Gleisanlagen* [PowerPoint-Presentation]. http://www.flora-deutschlands.de/Dateien_2015/Brandes-Flora%20auf%20staedtischen%20Bahngleisen.pdf

Bundesstiftung Baukultur. (2019). *Erbe—Bestand—Zukunft* (No. 3; Baukultur Bericht 2018/19, p. 180). Bundesstiftung Baukultur (BSBK). https://www.bundesstiftung-baukultur.de/sites/default/files/medien/76/downloads/baukulturbericht201819.pdf

Chai, H., Rodier, C., Song, J., Zhang, M., & Jaller, M. (2020). *The Impacts of Automated Vehicles on Center City Parking Demand*. 30. https://doi.org/10.7922/G2X928J1

DeStatis. (2020, September 11). *Press release: Pkw-Dichte in Deutschland in den vergangenen zehn Jahren um 12 % gestiegen*. Statistisches Bundesamt. https://www.destatis.de/DE/Presse/Pressemitteilungen/2020/09/PD20_N055_461.html

Easyride. (n.d.a). *Szenarien 2030+—EASYRIDE - automatisiertes und vernetztes Fahren im städtischen Kontext*. https://www.easyridemuenchen.info/zukunft/szenarien-2030.html

Easyride. (n.d.b). *Über das Projekt—EASYRIDE - automatisiertes und vernetztes Fahren im städtischen Kontext*. https://www.easyridemuenchen.info/easyride/ueber-das-projekt.html

Engel, H., Hensley, R., Knupfer, S., & Sahdev, S. (n.d.). *How electric vehicles could change the load curve | McKinsey*. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-potential-impact-of-electric-vehicles-on-global-energy-systems

Estepa, R., Estepa, A., Wideberg, J., Jonasson, M., & Stensson-Trigell, A. (2017). More Effective Use of Urban Space by Autonomous Double Parking. *Journal of Advanced Transportation*, *2017*, e8426946. https://doi.org/10.1155/2017/8426946

European Court of Auditors. (2018). *Combating desertification in the EU: a growing threat in need of more action* (No. 33; p. 65). European Court of Auditors.

European Environment Agency. (n.d.). *Greenhouse gas emissions from transport in Europe—European Environment Agency* [Indicator Assessment]. Retrieved 10 April 2021, from https://www.eea.europa.eu/data-and-maps/indicators/transport-emissions-of-greenhouse-gases-7/assessment

Fischer, A. (2020a, October 12). *Vollautomatisiertes und fahrerloses Parken kommt an den Flughafen Stuttgart [press report]*. Bosch Media Service. https://www.bosch-presse.de/pressportal/de/de/apcoa-bosch-und-mercedes-benz-arbeiten-am-weltweit-ersten-serieneinsatz-von-automated-valet-parking-am-flughafen-stuttgart-219648.html

Fischer, A. (2020b, October 12). *Weltpremiere: Bosch und Daimler erhalten Zulassung für fahrerloses Parken ohne menschliche Überwachung [press report]*. Bosch Media Service. https://www.bosch-presse.de/pressportal/de/de/weltpremiere-bosch-und-daimler-erhalten-zulassung-fuer-fahrerloses-parken-ohne-menschliche-ueberwachung-194624.html

Fraedrich, E., Kröger, L., & Bahamonde-Birke, F. (2017). *Automatisiertes Fahren im Personen-und Güterverkehr—Auswirkungen auf den Modal-Split, das Verkehrssystem und die Siedlungsstrukturen* (p. 63). https://www.emobil-sw.de/fileadmin/media/e-mobilbw/Publikationen/Studien/Studie_AutomatisiertesFahren.pdf

Friedrich, B. (2015). *Verkehrliche Wirkung autonomer Fahrzeuge*. Technische Universität Braunschweig, Institut für Verkehr und Stadtbauwesen.

Friedrich, M., & Hartl, M. (2017). Wirkungen autonomer Fahrzeuge auf den städtischen Verkehr. *Tagungsbericht Heureka*, *17*, 14.

GEO-NET Umweltconsulting GmbH, & Gross, G. (2014). *Stadtklimagutachten—Analyse der klimaökologischen Funktionen für das Stadtgebiet von Nürnberg*. https://www.nuernberg.de/imperia/md/umweltamt/dokumente/klima_energie/klimaanalyse-nuernberg_gutachten_rev01_komp_ohnekarten.pdf

German Federal Environmental Agency. (2020, September 14). *Marktdaten: Bereich Mobilität* [Text]. Umweltbundesamt; Umweltbundesamt. https://www.umweltbundesamt.de/daten/private-haushalte-konsum/konsum-produkte/gruene-produkte-marktzahlen/marktdaten-bereich-mobilitaet

GIVT mbH. (n.d.). *GIVT mbH - Pilotprojekt München*. https://www.givt.de/index.php/de/pilotprojekt-muenchen

Hagen, T., & Reining, M. (2019). *Übersicht über mögliche ökonomische Auswirkungen von City-Mauts* (p. 59). Research Lab for Urban Transport, Frankfurt University of Applied Sciences. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3474367

Human, S. (2019, August 6). *Sensoren gegen den Parkplatzfrust: Parkraumbewirtschaftung mit System*. https://www.industry-of-things.de/sensoren-gegen-den-parkplatzfrust-parkraumbewirtschaftung-mit-system-a-852225/

INRIX. (2020, March 9). *Press release: INRIX Verkehrsstudie: Stau verursacht Kosten in Milliardenhöhe*. Inrix. https://inrix.com/press-releases/2019-traffic-scorecard-german/

Jünemann, R., Künne, B., & Eller, J. (2012). Technisch effizient gestalten und ökonomisch optimieren Innovative Ansätze zur Kostenreduzierung von automatisierten Parksystemen. *F H Fördern und Heben*, *07–08*, 33.

Kickhöfer, B. (2017). *Der Einfluss von autonomen Fahrzeugen auf das Mobilitätsverhalten*. https://elib.dlr.de/117662/2/BenjaminKickhoefer_EinflussMobilitaetsverhaltenAF_v03_clean.pdf

Kizlauskas, S. (2011). Bodennutzungsflächen in München. *Münchner Statistik, 1. Quartalsheft, Jahrgang 2011*, 9.

Klug, S. (2020, November 27). *Expert interview* [Telephone call].

Knie, A., Canzler, W., & Ruhrort, L. (2019). *Autonomes Fahren im Öffentlichen Verkehr – Chancen, Risiken und politischer Handlungsbedarf* (p. 53). https://www.gruene-hamburg.de/wp-content/uploads/2019/04/Autonomes_Fahren_Gutachten_030419.pdf

Köster, C., & Harlos, L. (2020, June 18). *Kostenfalle Supermarktparkplatz: Das sind die Erfahrungen der Mitglieder*. https://www.adac.de/der-adac/regionalclubs/nrw/supermarktparkplatz/

Kraftfahrt-Bundesamt (KBA)- Federal Motor Transport Authority. (n.d.). *Neuzulassungen—Jahresbilanz der Neuzulassungen 2018*. Retrieved 18 March 2021, from https://www.kba.de/DE/Statistik/Fahrzeuge/Neuzulassungen/n_jahresbilanz.html

Krass, S. (2020, January 21). München: Lob und Kritik für Großmarkthallen-Pläne. *Süddeutsche.de*. https://www.sueddeutsche.de/muenchen/muenchen-grossmarkthalle-lob-kritik-1.4766039

Krass, S. (2021, February 4). München: Neues Quartier ‘Orleanshöfe’ am Ostbahnhof. *Süddeutsche.de*. https://www.sueddeutsche.de/muenchen/muenchen-haidhausen-bauplaene-orleanshoefe-1.5194552

Landesamt für Umwelt, Landwirtschaft und Geologie, Freistaat Sachsen. (n.d.). *Boden. Leben. Zukunft.* (p. 11). Landesamt für Umwelt, Landwirtschaft und Geologie, Freistaat Sachen. https://www.lfulg.sachsen.de/download/lfulg/Roll-ups_Boden_web.pdf

Landeshauptstadt München. (n.d.-a). *Das sind Münchens Sommerstraßen 2021*. muenchen.de. Retrieved 2 February 2021, from https://www.muenchen.de/freizeit/aktuell/temporaere-fussgaengerzonen-weitere-sommerstrassen-kommen.html

Landeshauptstadt München. (n.d.-b). *Parkzonen, Parklizenzen, Parkausweise*. muenchen.de. Retrieved 4 April 2021, from https://www.muenchen.de/verkehr/autos/parken/parkzonen-parklizenzen.html

Landeshauptstadt München. (2019). *Entwicklung Viehhofgelände* (Sitzungvorlage No. 14-20 / V 15268; p. 19). Referat für Stadtplanung und Bauordnung der Landeshauptstadt München. https://www.ris-muenchen.de/RII/RII/DOK/SITZUNGSVORLAGE/5523678.pdf

Landeshauptstadt München. (2020a). *Fortschreibung des Berichtes zur Entwicklung-des Kfz-Bestandes in München*. https://www.ris-muenchen.de/RII/RII/DOK/SITZUNGSVORLAGE/5999368.pdf

Landeshauptstadt München. (2020b, June 23). *Jahreswirtschaftsbericht 2020*. Landeshauptstadt München.

https://www.muenchen.de/rathaus/Stadtverwaltung/Referat-fuer-Arbeit-und-Wirtschaft/News/jwb.html

Landeshauptstadt München. (n.d.c). *Anwohnergaragen*. Landeshauptstadt München. https://www.muenchen.de/rathaus/error-pages/error-404.html

Landeshauptstadt München. (n.d.d). *Flex-Parken*. Landeshauptstadt München. https://www.muenchen.de/rathaus/error-pages/error-404.html

Landeshauptstadt München. (n.d.e). *Straßenauskunft—Übersichtskarte Parkraummanagement*. Landeshauptstadt München. https://www.muenchen.de/rathaus/Stadtverwaltung/Kreisverwaltungsreferat/Verkehr/Parkraummanagement/Strassenauskunft.html

Litman, T. (2021). *Implications for Transport Planning* (p. 46). Victoria Transport Policy Institute. https://www.vtpi.org/avip.pdf

llorca, C., & Moeckel, R. (2019). Effects of scaling down the population for agent-based traffic simulations. *Procedia Computer Science*, *151*, 782–787. https://doi.org/10.1016/j.procs.2019.04.106

Lödige Industries. (n.d.-a). *DOKK1 | Aarhus | Lödige Industries*. Retrieved 1 April 2021, from https://www.lodige.com/en-me/products/car-park-solutions/references/dokk1-aarhus/

Lödige Industries. (n.d.b). *Vollautomatische Parksysteme | Lödige Industries*. https://www.lodige.com/de-de/produkte/parkloesungen/parksysteme/

Malysheva, E., & Generalova, E. (2020). Adaptive reuse of parking in the cities of the future. *IOP Conference Series: Materials Science and Engineering*, *775*, 012049. https://doi.org/10.1088/1757-899X/775/1/012049

Manville, M., & Shoup, D. (2010). Parking requirements as a barrier to housing development: Regulation and reform in Los Angeles. *University of California Transportation Center, University of California Transportation Center, Working Papers*.

Marsden, G. (2014). Parking Policy. In *Transport and Sustainability* (Vol. 5, pp. 11–32). Emerald Group Publishing Limited. https://doi.org/10.1108/S2044-994120140000005016

Mockus, R., & Bartulis, V. (2009). The solutions to the problem of temporary vehicle parking in the city. The analysis of vehicle parking time and costs. *Mokslas – Lietuvos ateitis / Science – Future of Lithuania*, *1*(6), 95–101. https://doi.org/10.3846/mla.2009.6.20

Moeckel, R., Huntsinger, L., & Donnelly, R. (2017). From Macro to Microscopic Trip Generation: Representing Heterogeneous Travel Behavior. *The Open Transportation Journal*, *11*(1). https://doi.org/10.2174/1874447801711010031

Mohnheim, H. (2018). Weniger Autos, selektive Autonutzung, Ausbau des Umweltverbundes – Energie-sparen als klimaschonender Trend, in: Fahrverbote, City-Maut, kostenloser öffentlicher Nahverkehr: Wege aus dem Verkehrskollaps? *ifo Schnelldienst*, *71*, 20.

Nobis, Claudia & Kuhnimhof, Tobias. (2018). *Mobilität in Deutschland – MiD Ergebnisbericht.* (p. 136). infas, DLR, IVT und infas 360 im Auftrag des Bundesministers für Verkehr und digitale Infrastruktur. http://www.mobilitaet-in-deutschland.de/pdf/MiD2017_Ergebnisbericht.pdf

Notz, J. N. (2017). *Die Privatisierung öffentlichen Raums durch parkende Kfz. Von der Tragödie einer Allmende –über Ursache, Wirkung und Legitimation einer gemeinwohlschädigenden Regulierungspraxis* (p. 116). IVP TU Berlin. https://www.ivp.tu-berlin.de/fileadmin/fg93/Dokumente/Discussion_Paper/DP10_Notz_Privatisierung_%C3%B6ffentlichen_Raums_durch_parkende_Kfz.pdf

Oslo Kommune. (2019). *The Car-free Livability Programme 2019*. https://www.oslo.kommune.no/getfile.php/13319592-1553857948/Content/Politics%20and%20administration/City%20development/

Car%20free%20city/The%20Car-free%20Livability%20Programme%202019.pdf

P+R München. (n.d.). *Anwohnergarage Donnersbergerstraße—Park + Ride München*. https://www.parkundride.de/de/donnersbergerstrasse.html

Pendleratlas—Statistik der Bundesagentur für Arbeit. (2020, June). https://statistik.arbeitsagentur.de/DE/Navigation/Statistiken/Interaktive-Angebote/Pendleratlas/Pendleratlas-Nav.html

Ringwald, R., de Wyl, C., & Schmidt, S. (2018). *Öffentlicher Raum ist mehr wert. Ein Rechtsgutachten zu den Handlungsspiel-räumen in Kommunen.* (No. 2; p. 68). Agora Energiewende. https://www.agora-verkehrswende.de/fileadmin/Projekte/2018/OEffentlicher_Raum_ist_mehr_wert/Agora_Verkehrswende_Rechtsgutachten_oeffentlicher_Raum.pdf

Robert, F., & Belz, J. (2018). *Mobilität in Deutschland – MiD Kurzreport Stadt München, Münchner Umland und MVV-Verbundraum. Studie* (p. 24). infas, DLR, IVT und infas 360 im Auftrag des Bundesministers für Verkehr und digitale Infrastruktur. https://muenchenunterwegs.de/content/657/download/kurzreport-2019.pdf

Sachverständigenrat für Umweltfragen. (2016). *Für eine aktive und umweltfreundliche Stadtmobilität: Wandel ermöglichen* (No. 6; Für eine aktive und umweltfreundliche Stadtmobilität: Wandel ermöglichen, p. 79). Sachverständigenrat für Umweltfragen. https://www.umweltrat.de/SharedDocs/Downloads/DE/01_Umweltgutachten/2016_2020/2020_Umweltgutachten_Kap_06_Stadtmobilitaet.pdf?__blob=publicationFile&v=6

Sieg, G. (2018). Politikoptionen für die Übergangsphase zur City-Maut, in: Fahrverbote, City-Maut, kostenloser öffentlicher Nahverkehr: Wege aus dem Verkehrskollaps? *ifo Schnelldienst*, *71*, 20.

Sieg, G. (2020). Das verschmähte Instrument der (Fernstraßen- oder City-) Maut. *List Forum für Wirtschafts- und Finanzpolitik*, *46*(2), 213–225. https://doi.org/10.1007/s41025-020-00197-x

Stadelmann, D. (2018). Lenken statt verbieten: Freie Fahrt und bessere Luft dank Maut, in: Fahrverbote, City-Maut, kostenloser öffentlicher Nahverkehr: Wege aus dem Verkehrskollaps? *ifo Schnelldienst*, *71*, 20.

Stadtrat, L. M. (2020). *Beschluss—Einleitung einer Städtebaulichen Entwicklungsmaßnahme (SEM) für den Münchner Norden*. Landeshauptstadt München. https://www.ris-muenchen.de/RII/RII/DOK/TOP/6147396.pdf

Statista. (2021, March 4). *Anzahl zugelassener Pkw in Deutschland von 1960 bis 2021*. Statista. https://de.statista.com/statistik/daten/studie/12131/umfrage/pkw-bestand-in-deutschland/

Stopka, U. (2019, January 14). *Parkraummanagement zur Sicherstellung der Parksituation im städtischen Raum*. https://www.forschungsinformationssystem.de/servlet/is/29145/

studioeuropa. (n.d.). *UTO*. UTO. Retrieved 2 March 2021, from https://www.utostadt.info/

Urban, T. (2018, Dezember). *Pontevedra: So funktioniert eine Stadt ohne Autos*. Süddeutsche.de. https://www.sueddeutsche.de/wirtschaft/pontevedra-fussgaenger-autos-1.4259542

Verkehr in München. (2020). Statistisches Amt der Landeshauptstadt München.

Weldu, M. K. (2018). *Urban planning: The potential role of shared autonomous vehicles in transforming our cities - based on a case study of Stavanger city centre* [University of Stevanger]. https://vegvesen.brage.unit.no/vegvesen-xmlui/handle/11250/2563532

Wikipedia. (2021). Pontevedra. In *Wikipedia*. https://en.wikipedia.org/w/index.php?title=Pontevedra&oldid=1020272386

Wittowsky, D. (2019, December 16). *Kollektive Parkinformation*. https://www.forschungsinformationssystem.de/servlet/is/37372/?clsId0=0&clsId1=0&clsId2=0&clsId3=0

Wöhr. (n.d.). *Fahrzeugzeichnungen—WOEHR_710-730*. https://woehr.de/files/uploads/woehr/downloads/datasheets/multiparker/de/WOEHR_710-730_DE.pdf

Wöhr + Bauer GmbH. (n.d.). *Anwohnertiefgarage Donnersbergerstrasse—Wöhr + Bauer GmbH*. https://woehrbauer.de/referenzen/anwohnertiefgarage-donnersbergerstrasse

Wu, M., Jiang, H., & Tan, C.-A. (2021). Automated Parking Space Allocation during Transition with both Human-Operated and Autonomous Vehicles. *Applied Sciences*, *11*(2), 855. https://doi.org/10.3390/app11020855

Yekollu, N. (2020). Impact of Autonomous Vehicles on Parking Spaces. *Journal of Architectural Environment & Structural Engineering Research*, *3*. https://doi.org/10.30564/jaeser.v3i1.1834

Appendix I – List of Experts

Expert	Position	Interviewed via	Date
Streifeneder, Julius	Head of Urban Planning & Architecture, Urban-standards	Video-Call	02.11.2020, 12.02.2021
Stjepanovic, Benjamin	Landeshauptstadt München	Phone-Call	01.12.2020
Sonntag, Kai	Landeshauptstadt München, Stadtentwicklungsplanung, Abteilung Verkehrsplanung, Gesamtstädtische Konzeptionen - PLAN I/31	Phone-Call	02.12.2020
Klug, Stefan	Landeshauptstadt München, Dipl.-Ing. Raumplanung (Stadtplaner ByAK), Verkehrsplanung, PLAN HA I/31	Phone-Call	27.11.2020
Schütte, Dr. Fabian	Landeshauptstadt München, Verkehrsplaner, Leitung Abteilung Forschung und Innovation bei Landeshauptstadt München, Mobilitätsreferat	Phone-Call	20.01.2021
Türck, Ulrich	Landeshauptstadt München, Baureferat	Phone-Call	10.12.2020
Maget, Christoph	Landesbaudirektion Bayern Zentrale Landesaufgaben Straße, Verkehr und IT-Systeme	E-Mail	11.02.2021, 24.02.2021
Eggeling, Axel	Real-Este Expert	Phone-Call	11.03.2021
Schock, Tobias	Economic Development Officer, Kirchheim bei München	Video-Call	09.03.2021
Rosendahl, Richard	Wöhr	Phone-Call, E-Mail	16.03.2021, 18.03.2021
Spreng, Robert	DB, Arbeitsgebietsleiter Eigentumsmanagement (CR.R O4-S(E1))	Video-Call	06.04.2021

Expert	Position	Interviewed via	Date
	Deutsche Bahn AG DB Immobilien Region Süd		
Kühn, Christian	DB Immobilien Kundenteam Vertrieb Leiter Arbeitsgebiet Produktionsmanagement (CR.RO1-S(P))	Video-Call	06.04.2021
Franz, Marek	LIDL, Immobilien, Region Immo Südost	Phone-Call	26.04.2021

Experts in addition requested: (classified according to sectors)
Discounter
Supermarkets
Technology companies
Parking garage constructor
Manufacturer of automatic parking systems
Parking space finder service
Automobile manufacturer
Companies with large open parking areas in Munich (off-street)

Appendix II – List of Areas

Parking	Parking [m²]	Coordinates GK4
Allach	3.725,58	4461098,534
Moosach	10.065,63	4462890,534
Moosach	13.286,42	4463178,534
Moosach	4.129,34	4463066,534
Moosach	6.002,96	4463370,534
Moosach	3.021,95	4462709,534
Moosach	2.062,20	4465342,534
Moosach	7.274,50	4465486,534
Moosach	2.522,07	4465654,534
Feldmoching	34.511,33	4466918,534
Feldmoching	13.384,37	4467902,534
Milbertshofen	4.380,10	4466807,534
Milbertshofen	3.445,64	4467278,534
Milbertshofen	3.679,08	4468094,534
Milbertshofen	2.793,31	4467996,534
Milbertshofen	2.967,44	4468206,534
Milbertshofen	2.455,61	4468318,534
Freimann	4.461,59	4469109,534
Freimann	26.584,24	4469277,534
Freimann	6.094,10	4469092,534
Freimann	7.177,81	4469604,534
Freimann	3.078,30	4469948,534
Freimann	2.283,11	4469956,534
Freimann	3.057,96	4470080,534
Freimann	21.447,78	4470212,534
Freimann	9.090,01	4470574,534
Freimann	9.185,76	4470840,534
Freimann	9.851,81	4470717,534
Freimann	51.302,37	4469518,534
Freimann	10.401,13	4469870,534
Freimann	21.668,39	4469374,534
Freimann	5.689,65	4469358,534
Schwabing	2.778,59	4470976,534
Schwabing	9.063,16	4470868,534
Schwabing	9.673,43	4469633,534
Aubing	29.987,63	4457188,533
Pasing	14.786,82	4457724,533
Pasing	4.548,56	4457988,533
Pasing	27.731,22	4457948,533
Pasing	25.716,13	4457876,533
Pasing	3.775,93	4460972,533
Pasing	3.945,39	4462082,533
Neuhausen	3.872,18	4464603,533
München, S.5	6.368,93	4465563,533
München, S. 5	7.407,29	4464899,533
München, S. 5	1.980,61	4464723,533
München, S. 5	10.639,23	4464467,533
München, S. 5	5.545,23	4465602,533
München, S. 5	1.974,38	4465061,533

München, S.4	9.022,89	4466675,533
München, S.7	4.194,09	4469029,533
München, S.8	5.611,52	4470214,533
Großhadern	30.705,18	4460962,533
Großhadern	30.849,30	4460866,533
Großhadern	8.057,05	4460882,533
Forstenried	14.362,88	4463241,533
Forstenried	10.291,00	4463337,533
Forstenried	4.289,57	4463089,533
Thalkirchen	3.026,05	4463821,533
Thalkirchen	8.478,51	4464481,533
Thalkirchen	5.014,54	4464786,533
Thalkirchen	2.322,21	4464970,533
Thalkirchen	6.227,40	4464982,533
Thalkirchen	8.910,19	4465482,533
Perlach	4.241,09	4470285,533
Perlach	5.041,33	4472776,533
Perlach	7.356,90	4472936,533
Perlach	6.405,74	4473672,533
Perlach	11.765,13	4473835,533
Perlach	46.826,24	4473771,533
Perlach	18.397,48	4473941,533
Perlach	34.533,28	4474245,533
Berg am Laim	5.506,16	4472152,533
Berg am Laim	2.332,33	4472440,533
Berg am Laim	7.441,23	4472768,533
Berg am Laim	2.428,59	4473592,533
Trudering	6.269,83	4474558,533
Trudering	2.060,76	4474766,533
Trudering	1.264,01	4474974,533
Trudering	2.799,29	4475294,533
Trudering	9.829,11	4476686,533
Untermenzing	17.082,37	4458634,534
Total:	**823.819,50**	
Road		
Großhadern	24.994,34	4460802,533
Großhadern	32.949,57	4461314,533
Großhadern	16.115,44	4461794,533
Großhadern	20.523,57	4463754,533
München, S. 5	24.004,13	4464253,533
München, S. 5	38.856,19	4463819,533
Perlach	43.728,02	4469660,533
Berg am Laim	57.718,63	4473313,533
Schwabing	13.077,83	4470096,534
Freimann	13.077,83	4471499,534
Freimann	24.699,59	4471899,534
Freimann	43.086,53	4472123,534
Total:	**352.831,67**	

Railway track		
Allach	78.740,26	4461378,534
Aubing	226.989,71	4458214,534
Obermenzing	18.581,84	4461016,534
Obermenzing	9.476,07	4461172,534
Obermenzing	13.497,42	4461374,534
Pasing	57.820,19	4460932,533
Pasing	9.610,24	4461760,533
Laim	27.253,11	4463570,533
Neuhausen	46.448,24	4464766,533
München, S. 5	10.178,42	4465064,533
München, S. 4	60.692,06	4465803,533
München, S. 5	7.295,86	4465670,533
München, S. 5	10.094,25	4466350,533
München, S. 5	9.239,01	4465576,533
München, S. 6	25.989,62	4466838,533
München, S. 9	47.994,92	4471028,533
Berg am Laim	63.273,12	4472776,533
Berg am Laim	156.556,26	4473393,533
Trudering	9.500,73	4474336,533
Trudering	17.729,40	4475144,533
Freimann	28.462,56	4470491,534
Freimann	13.088,25	4469462,534
Milbertshofen	18.070,98	4468810,534
Milbertshofen	12.350,21	4468066,534
Milbertshofen	23.230,50	4467235,534
Feldmoching	20.052,56	4465990,534
Moosach	67.134,87	4464234,534
Total:	**1.089.350,66**	
Industrial		
Moosach	31.018,05	4462510,534
Moosach	13.286,42	4463190,534
Moosach	143.912,79	4462910,534
Moosach	26.143,79	4463118,534
Neuhausen	68.778,04	4464586,533
Neuhausen	21.914,44	4464717,533
München, S. 5	3.907,99	4464522,533
Milbertshofen	32.494,85	4467621,534
Milbertshofen	31.025,16	4469493,534
Freimann	21.447,78	4470197,534
Freimann	40.705,93	4470901,534
Berg am Laim	50.777,53	4473139,533
Trudering	28.430,08	4475267,533
Perlach	28.302,45	4474406,533
Total:	**542.145,30**	
Public utilities		
München, S. 8	33.993,20	4470515,533
München, S. 9	90.724,69	4471658,533
München	12.766,57	4466904,534
München, S. 5	64.354,10	4464242,533
Total:	**201.838,56**	

Car parks (small selection)		
München S. 5	2.673,08	4464585,533
München S. 5	2.657,95	4467581,533
Thalkirchen	5.001,97	4464653,533
Milbertshofen	3.510,04	4466986,534
Total:	**13.843,04**	
Olympic harp		
Milbertshofen	97.326,00	4465997,534
Total area (m²):	**3.023.828,73**	

Appendix III - Trip Durations Pattern

pattern (min)	0	5	10	15	20	25	30	35	40	45	50	55	60	Sum	0-15 min	Share (0	60+ shar
State of the art																	
education---home	120	61	23	11	1	0	0	0	0	0	0	0	0	216	204	0.94	
home---education	118	58	31	8	1	0	0	0	0	0	0	0	0	216	207	0.96	
home---other	3824	5975	4586	2212	715	155	24	4	0	0	0	0	0	17495	14385	0.82	
home---shopping	3214	5515	792	57	6	1	0	0	0	0	0	0	0	9585	9521	0.99	
home---work	660	1888	1621	730	186	23	4	0	0	0	0	0	0	5112	4169	**0.82**	
other---home	3834	5933	4552	2233	683	168	27	2	0	0	0	0	0	17432	14319	0.82	
other---other	886	3224	3727	2375	706	155	18	2	0	0	0	0	0	11093	7837	0.71	
shopping---home	3171	5500	849	53	5	0	0	0	0	0	0	0	0	9578	9520	0.99	
work---home	612	1919	1633	717	192	21	2	1	0	0	0	0	0	5097	4164	0.82	
work---other	577	2325	1625	491	71	13	0	0	0	0	0	0	0	5102	4527	0.89	
Average trip duration [h]	00:09:22																
Garage 1																	
dropOffPoint---garage	4	13	19	34	27	26	16	19	15	13	15	18	997	1216	36	0.03	0.82
education---home	32	23	11	8	6	6	11	9	8	10	10	9	219	362	66	0.18	0.60
garage---home	0	6	24	28	28	23	16	10	7	7	8	11	1006	1174	30	0.03	0.86
garage---other	1	4	4	2	7	3	0	0	0	0	0	0	38	59	9	0.15	0.64
garage---work	0	1	1	0	0	1	0	0	0	0	0	0	49	52	2	0.04	0.94
home---dropOffPoint	58	212	314	324	228	166	132	99	71	66	47	34	465	2216	584	0.26	0.21
home---education	45	22	19	9	13	13	15	28	14	17	24	19	127	365	86	0.24	0.35
home---garage	0	1	3	4	2	0	0	0	2	0	0	1	65	78	4	0.05	0.83
home---other	994	1603	1635	1373	1092	848	766	620	552	429	385	319	6588	17204	4232	0.25	0.38
home---shopping	593	1896	1524	734	450	272	245	148	137	129	104	117	1607	7956	4013	0.50	0.20
home---work	258	961	1425	1239	974	636	417	267	148	112	87	62	632	7218	2644	**0.37**	0.09
other---garage	0	5	5	9	5	0	1	0	1	0	0	0	546	572	10	0.02	0.95
other---home	1026	1763	1580	1246	919	705	617	446	441	346	284	270	6201	15844	4369	0.28	0.39
other---other	140	545	886	1161	1260	1201	993	800	733	583	484	388	6643	15817	1571	0.10	0.42
shopping---home	611	1946	1421	706	423	243	175	152	128	123	109	101	1497	7635	3978	0.52	0.20
work---home	135	528	842	817	652	513	349	277	198	156	121	122	2268	6978	1505	0.22	0.33
work---other	122	660	909	652	435	257	180	142	111	107	95	100	1495	5265	1691	0.32	0.28
Average trip duration [h]	01:21:57																
Garage 2																	
dropOffPoint---garage	30	67	98	96	60	51	37	45	51	46	41	33	1336	1991	195	0.10	0.67
education---home	31	22	17	10	2	7	10	14	8	11	3	7	220	362	70	0.19	0.61
garage---home	14	51	51	32	20	14	17	24	15	11	14	10	1618	1891	116	0.06	0.86
garage---other	2	11	9	0	0	0	1	0	0	1	0	0	133	157	22	0.14	0.85
garage---work	0	1	2	0	1	0	2	0	2	0	2	0	119	129	3	0.02	0.92
home---dropOffPoint	79	268	344	414	273	198	133	84	86	69	55	35	582	2620	691	0.26	0.22
home---education	48	27	9	9	14	16	14	22	18	23	15	19	132	366	84	0.23	0.36
home---garage	0	8	6	4	1	2	3	0	2	2	1	3	326	358	14	0.04	0.91
home---other	1018	1634	1606	1410	1131	951	798	600	505	469	380	320	6589	17411	4258	0.24	0.38
home---shopping	610	1943	1514	804	468	323	230	167	144	138	97	103	1566	8107	4067	0.50	0.19
home---work	255	961	1440	1320	952	702	420	268	159	91	94	61	572	7295	2656	**0.36**	0.08
other---garage	6	9	8	7	5	3	3	7	14	5	6	6	1458	1537	23	0.01	0.95
other---home	1042	1810	1555	1296	983	723	666	488	413	369	320	287	6163	16115	4407	0.27	0.38
other---other	145	555	881	1282	1274	1176	1069	844	690	598	521	405	6645	16085	1581	0.10	0.41
shopping---home	661	1920	1483	765	430	291	217	171	147	116	102	83	1425	7811	4064	0.52	0.18
work---home	136	542	838	778	700	528	380	258	218	161	138	118	2310	7105	1516	0.21	0.33
work---other	129	640	890	717	479	288	188	127	134	78	108	73	1516	5367	1659	0.31	0.28
Average trip duration [h]	01:24:23																
Garage 24																	
dropOffPoint---garage	1212	1197	563	334	216	149	123	88	75	43	62	62	621	4745	2972	0.63	0.13
education---home	38	27	15	11	10	6	10	6	11	10	5	11	259	419	80	0.19	0.62
garage---education	3	5	3	2	2	0	0	0	0	1	1	2	78	97	11	0.11	0.80
garage---home	1204	1381	693	501	371	263	198	151	146	165	146	100	3942	9261	3278	0.35	0.43
garage---other	379	449	282	233	157	101	100	72	73	97	78	47	2500	4568	1110	0.24	0.55
garage---shopping	22	33	22	11	5	7	2	0	2	7	3	5	130	249	77	0.31	0.52
garage---work	249	362	217	147	111	78	59	50	55	60	49	30	1380	2847	828	0.29	0.48
home---dropOffPoint	207	532	635	542	450	321	221	167	154	113	93	68	1445	4948	1374	0.28	0.29
home---education	39	25	15	8	6	10	9	25	11	12	16	22	163	361	79	0.22	0.45
home---garage	1301	1423	680	422	259	174	163	129	135	104	66	95	1034	5985	3404	0.57	0.17
home---other	777	1265	1328	1300	963	810	816	620	562	515	448	358	8450	18212	3370	0.19	0.46
home---shopping	461	1502	1422	932	664	426	323	262	230	187	190	170	2984	9753	3385	0.35	0.31
home---work	199	848	1271	1258	975	731	447	346	176	117	119	95	872	7454	2318	**0.31**	0.12
other---garage	359	593	446	316	237	188	159	118	114	86	96	83	1663	4458	1398	0.31	0.37
other---home	871	1415	1364	1187	928	707	677	553	477	437	391	322	7515	16844	3650	0.22	0.45
other---other	115	414	657	902	1008	1032	949	915	771	620	534	474	9591	17982	1186	0.07	0.53
shopping---home	491	1522	1442	963	597	422	339	267	242	194	157	167	2563	9366	3455	0.37	0.27
work---home	104	420	677	735	632	548	411	346	289	234	174	158	3557	8285	1201	0.14	0.43
work---other	97	492	770	652	504	384	282	224	174	125	121	116	2391	6332	1359	0.21	0.38
Average trip duration [h]	01:33:44																

Park & Ride																	
dropOffPoint---garage	932	1062	555	344	259	167	115	84	95	57	57	39	661	4427	2549	0.58	0.15
education---garage	4	9	2	1	0	1	2	0	0	0	0	0	4	23	15	0.65	0.17
education---home	31	20	9	11	4	4	2	3	4	4	1	1	15	109	60	0.55	0.14
education---parkAndRide	1	0	0	0	0	0	0	0	0	0	0	0	2	3	1	0.33	0.67
garage---education	1	4	2	3	1	2	0	1	0	0	0	0	15	29	7	0.24	0.52
garage---home	891	1257	750	448	220	224	161	154	106	99	84	60	2693	7147	2898	0.41	0.38
garage---other	315	495	344	226	165	115	104	79	60	46	46	36	1946	3977	1154	0.29	0.49
garage---shopping	16	51	35	20	7	9	7	7	0	1	5	3	194	355	102	0.29	0.55
garage---work	202	333	246	143	98	82	60	44	36	22	22	21	1057	2366	781	0.33	0.45
home---dropOffPoint	191	538	679	623	452	315	222	178	129	110	78	67	682	4264	1408	0.33	0.16
home---education	50	14	6	3	5	3	1	4	3	5	4	1	4	103	70	0.68	0.04
home---garage	733	816	408	228	183	120	103	112	88	61	35	37	470	3394	1957	0.58	0.14
home---other	750	1152	1210	1153	953	759	663	550	495	403	346	307	3992	12733	3112	0.24	0.31
home---parkAndRide	54	159	219	213	218	171	162	135	131	108	95	104	3571	5340	432	0.08	0.67
home---shopping	465	1367	1236	757	476	318	221	180	128	100	79	66	681	6074	3068	0.51	0.11
home---work	166	617	1057	1034	810	543	350	225	148	90	59	53	333	5485	1840	0.34	0.06
other---garage	399	664	469	352	266	193	169	149	115	97	101	75	1219	4268	1532	0.36	0.29
other---home	818	1269	1323	1130	881	684	582	521	436	387	314	269	4137	12751	3410	0.27	0.32
other---other	102	373	700	939	1065	1102	944	852	682	591	483	398	4674	12905	1175	0.09	0.36
other---parkAndRide	23	33	54	71	80	68	102	57	57	56	59	48	2417	3125	110	0.04	0.77
parkAndRide---dropOffPoin	9	24	33	36	27	16	20	13	7	10	6	6	229	436	66	0.15	0.53
parkAndRide---education	2	0	0	0	0	0	0	0	0	0	0	0	1	3	2	0.67	0.33
parkAndRide---home	13	27	58	62	44	41	46	40	33	29	24	18	1538	1973	98	0.05	0.78
parkAndRide---other	13	24	47	55	42	51	64	66	52	50	34	49	2889	3436	84	0.02	0.84
parkAndRide---parkAndRide	888	120	55	62	45	64	45	19	27	28	32	35	1995	3415	1063	0.31	0.58
parkAndRide---shopping	4	15	19	25	17	12	13	8	11	14	8	9	512	667	38	0.06	0.77
parkAndRide---work	12	65	94	99	77	53	30	35	16	23	14	7	317	842	171	0.20	0.38
shopping---garage	10	21	11	9	7	14	7	7	6	7	2	1	22	124	42	0.34	0.18
shopping---home	457	1426	1248	748	428	296	226	178	149	101	93	74	772	6196	3131	0.51	0.12
shopping---parkAndRide	7	18	18	16	18	13	16	28	20	12	23	8	317	514	43	0.08	0.62
work---garage	27	50	51	46	33	28	38	25	32	17	18	10	204	579	128	0.22	0.35
work---home	72	371	605	704	648	507	410	315	220	179	144	123	1529	5827	1048	0.18	0.26
work---other	111	478	726	634	483	348	242	166	127	107	93	82	898	4495	1315	0.29	0.20
work---parkAndRide	6	22	51	57	45	28	40	42	32	21	20	15	1127	1506	79	0.05	0.75
Average trip duration [h]	01:31:33																

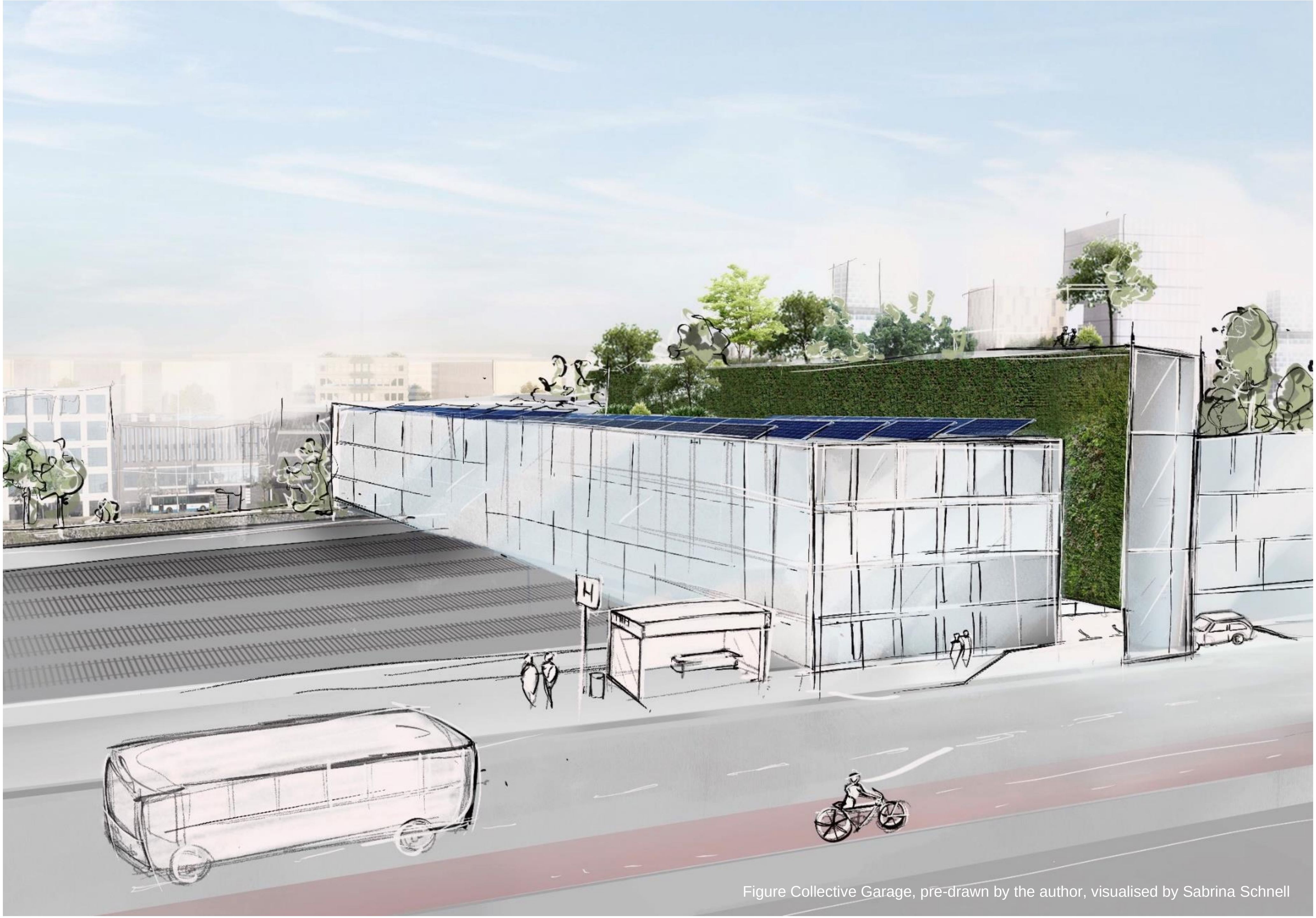


Figure Collective Garage, pre-drawn by the author, visualised by Sabrina Schnell