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MASTER'S THESIS

Evaluation of the Impact on Land Use and Transport Flows with the Construction of second Stammstrecke in Munich

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With the steady rise of population in Munich over the last decade in general and last couple of years in particular, the public transportation system has been under considerable burden to cater for the mobility demand of commuters. In order to alleviate the congestion on existing public transportation system, especially S-Bahn network, a second core line, 2nd Stammstrecke, is being built parallel to the existing one. 2nd Stammstrecke is a significant infrastructural development that is predicted to have considerable effect on the transport flows and the land use patterns. Therefore, analyzing this impact would go a long way toward establishing the efficacy of the project.

The inherent linkage between land use and transportation has been traditionally modeled at a macroscopic level where every household in a zone is represented by aggregated travel time and travel cost matrices. With every individual having a unique mobility pattern, this generalized approach has been unable to properly consider the varying mobility needs of an individual from the same household. The microscopic integrated land use and transport modeling aims to overcome this shortcoming and would represent the individual travel experiences that in turn play decisive role in housing location choice of a household.

The research in this thesis aims to measure the impact of the implementation of a second parallel express line going through central Munich on the regional transport flows as well as land use. The study area will be the Munich Metropolitan Area since the 2nd Stammstrecke line is projected to influence regional flows concerning the whole metropolitan area. The land use model, SILO, and travel demand model, MATSim will be integrated and implemented in the thesis work. Two other alternative



scenarios will be considered in addition to the 2nd Stammstrecke construction and in the end, the suitability and the plausibility of the project will be determined.

The student will present intermediate results to the mentor(s) ((Prof. Dr.-Ing. Rolf Moeckel), perhaps additional mentors) in the 5th, 10th, 15th and 20th week.

The student must hold a 20-minute presentation with a subsequent discussion at the most two months after the submission of the thesis. The presentation will be considered in the final grade in cases where the thesis itself cannot be clearly evaluated. The student will submit one copy for each mentor plus one copy for the library of the Focus Area Mobility and Transport Systems. Furthermore, the student will provide a PDF file of the master thesis for the website of this research group. In exceptional cases (such as copyright restrictions do not allow publishing the thesis), the library copy will be stored without public access and the PDF will not be uploaded to the website.

Prof. Dr.-Ing. Rolf Moeckel

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Abstract

The metropolitan region of Munich is experiencing steady urban growth. One key element of sustainable urban development is a reliable and efficient transportation system. In order to cater for the growing urban transportation demand in the region and alleviate burden on the current transit network, a second central line, called the second Stammstrecke, is being built parallel to the current one. The revamped S-bahn network will further see inclusion of new lines with fewer stops and re-routing of some of the existing lines.

This thesis aims to study the land use and transport effects of the proposed S-bahn network under second Stammstrecke project. A state of the art model, consisting of the land use model, called SILO, and a transport model, named MATSim, is used to forecast the effects by developing two scenarios and comparing them with the traditional base scenario. First developed scenario is the implementation of the 2nd Stammstrecke while the second one consists of exogenous addition of housing along with the 2nd Stammstrecke. The input data, mainly the transport one, is modified and prepared for the three scenarios and is then fed into the model for the implementation.

The parameters evaluated are modal split (transit), population changes, employment, average price, accessibility (auto and transit) and car ownership at different levels of resolution. The scenario analysis shows that although improvement in modal split and reduction in car ownership for the scenario one (2nd Stammstrecke scenario) is achieved, the overall effect is insubstantial, with other parameters showing no effect of second Stammstrecke. The results also highlight the importance of promoting transit-oriented development in accentuating the effects of a major transit development project like the second Stammstrecke since the parameters like population changes at the zonal level and average price respond appreciably to the scenario two (2nd Stammstrecke plus additional housing scenario).

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Abbreviations

2SS: *2nd Stammstrecke*

DB: *Deutsche Bahn* (German Railway)

GIS: Geographic Information System

HBf: *Hauptbahnhof* (Central Station)

ILUT: Integrated Land Use and Transport

LUTI: Land Use and Transport Interaction

MMA: Munich Metropolitan Area

MVV: *Münchner Verkehrs- und Tarifverbund* (Munich Transport and Tariff Association)

S-bahn: *Stadtschnellbahn* (Sub-urban rapid train)

TOD: Transit Oriented Development

U-bahn: *Untergrundbahn* (Subway)

Chapter 1

Introduction

Urban population growth is one of the challenges that has recently hit Germany in general and the metropolitan region of Munich, in particular. At the turn of millennium, the population levels of the country were already shrinking but the latter half of last decade resulted in population levels rising again. Naturally, the growing population has resulted in increased demand for housing and developable land. Munich metropolitan area, being the hub of industry and economic development in Germany, has witnessed steady growth over the past decade or so. The public transportation system of the region has also come under severe pressure to serve the needs of riders. The S-bahn network was designed to cater for some 250,000 passengers per day but currently over 800,000 passengers board the Munich S-bahn (2.Stammstrecke Muenchen, 2017b).

In order to handle such heavy demand in the longer run, the S-bahn network will be provided with another central line which will run in parallel to the existing Stammstrecke. The east-west directed line will only serve the core stops from the existing Stammstrecke, The idea is to have a travel time reduction, not only when travelling to the central area of Munich but more significantly when travelling from one side of the metropolitan area to another.

The demographic of Munich metropolitan area has experienced a gradual change over the past decade or so. Mixed type of land use has been a hallmark of the region and that is why it has been able to grow sustainably. A highly integrated public transportation network in and around the heart of the Munich metropolitan area has always been one of the popular mode choices. Travel budgets go a long way towards deciding which mode of transportation should be used for daily commute and owing to the presence of a well-connected transit network, many people are willing to use the public transport even for travelling from one part of the region to another. Moreover, existence and further development of housing/office space near the major transit stops has further aided to the usage of PuT.

Estimated to start functioning in 2026, the 2nd Stammstrecke is a major infrastructural development that is predicted to have a reasonable impact on not only traffic flows but also on land-use patterns. According to 2008 'Mobility in Deutschland' report, 21 percent of total trips per day is accounted by public transportation. Along with car, public transportation is the most popular mode for travelling long distance for commuting. Around 12.9 million-kms net distance per day is catered

by the Munich public transportation services (Mobilität in Deutschland, 2010).

Little to no research or modeling seems to have been done to evaluate the impacts of this mega project. There is some work done by the Deutsche Bahn with regards to modeling the possible travel impacts but the probable effects of the revamped transportation network with 2nd Stammstrecke in place on land-use patterns and changes have not really been modeled.

The goal of the research in this thesis is to establish the land use-transport interaction in a mutual feedback system to holistically establish the potential impact of second Stammstrecke. The integrated modeling will be done at a microscopic level, instead of adopting the traditional macroscopic approach. Scenario development will be done to compare the effects of second Stammstrecke on land use and transport parameters in order to qualitatively establish the overall impact of the project.

1.1 Thesis Outline

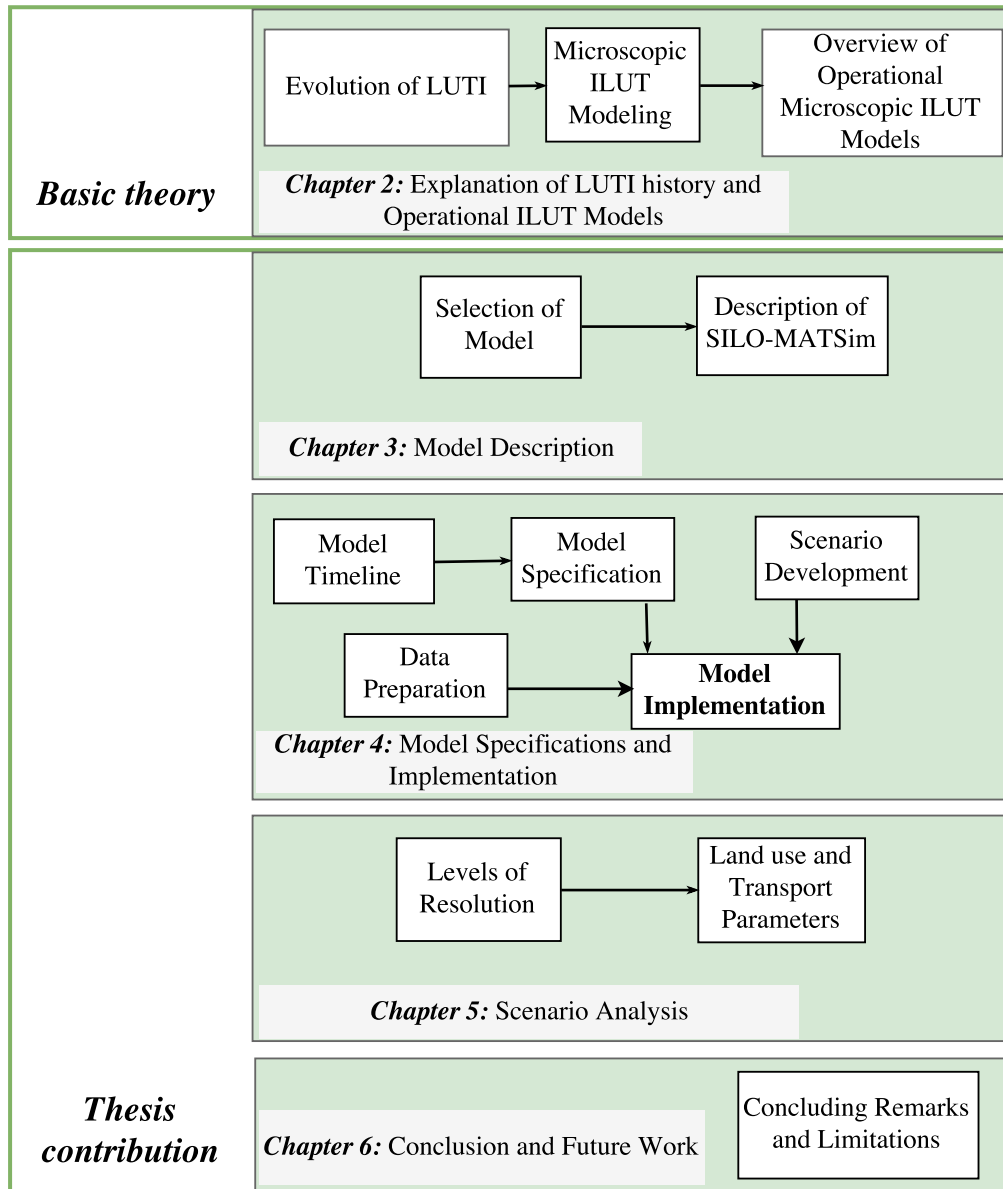


Figure 1.1: Overview of the thesis

Chapter 2

Literature Review

This chapter will briefly describe the historical development in the field of land use and transport interactions. Moreover, brief description of microsimulation approach ILUT models would be included. To conclude, a glimpse into a few operational microscopic ILUT models would also be provided.

2.1 Evolution of Research on Land Use and Transport Interactions Modeling

With the growing settlements and general rise in population around the world from mid 20th century, the major urban cities faced the challenges of dealing with traffic congestion, delays and jams. Reliance on automobile for undertaking most trips saw an increase in traffic on roads and the transit services still in their infancy were not as adequate as some of the other motorized modes.

2.1.1 Aggregate-based Macroscopic Modeling

The urban planners had realized the importance of accessibility for the land development and found a positive relationship between accessibility and the potential of urban growth (Hansen, 1959). Based on relationship between land use and residential development, Hansen proposed a land-use model that could be used to check the impact of a proposed infrastructural change on the accessibility to various activities. The model was based on the concept of development ratio and accessibility index. The work from Hansen popularized further research on land use and transportation interaction. Lowry (1964) built and applied a first-generation model to the data of Pittsburgh, Pennsylvania that was based on the concept of gravitation. The model was based on zonal analysis; the amount and distribution of land use activities, including housing, employment etc, was fed into the model. The output yields the estimated employment and population growth and its distribution within the zones. The iterative process goes on until an equilibrium between residential population and employment opportunities is reached. Stimulated by the work of Lowry, Crecine in 1968, developed TOMM (Time Oriented Metropolitan Model) for the Pittsburgh Community Renewal Program. The model employed largely the Lowry Model with the major addition being the introduction of effect of time increment on forecasting.

TOMM also disaggregated the population into different socio-economic groups such as blue-collar and white collar workers in order to better explain the model (Goldner, 1971; Briassoulis et al., 2000). Goldner (1971) also utilized the Lowry model framework and designed PLUM (Projective Land Use Model) for the San Francisco region. The modifications in the PLUM that were incorporated were the creation of network times by generation of skims, spatial disaggregation of trip types, introduction of zone-specific demographic data (workers per household, population per household and population per worker) and simulation of trips, compared to the estimation of them according to accessibility index (as per Lowry's Model). Wilson (1970) introduced the concept of entropy in ILUT modeling. The model addresses spatial interaction approach and tries to maintain the equilibrium by maximizing the entropy of all the zonal activities.

The 1970s saw utility-based modeling gain popularity in ILUT modeling. The microscopic nature of utility based modeling differed from the aggregated gravity and spatial interaction models in the sense that it focused on modeling the complex choice behavior decisions pertaining to land use and transport at microscopic level (Acheampong and Silva, 2015).

Moving onto 1980s, Wegener (1982) developed an ILUT model called IRPUD for the Dortmund region at University of Dortmund. IRPUD took into account the economic and demographic growth of the area and tried to address the location decisions of all the land use actors, the associated migration and commute patterns and the development of land use. IRPUD was considered a landmark ILUT model because it was one of the first models adopting the microscopic ILUT modelling (explained in subsection 2.1.2) going around at that time. The later modifications of IRPUD transformed it into a completely microscopic disaggregated ILUT model.

Around the same time period, Putman (1976, 1983) designed ITLUP that relied on gravity approach. Aggregated and macroscopic in nature, the work on ITLUP started in early 1970s and continued through the following decades with development of DRAM (Disaggregated Residential Allocation Model) and EMPAL (Employment Allocation Model). EMPAL uses the data about job and population location and forecasts the trends and future location of jobs. Using the same set of data plus the EMPAL's forecast of future location of employment, DRAM predicts the future location of households (Putman, 1991). Similarly, Mackett (1983) produced LILT (Leeds Integrated Land Use Transport Model) that, like its predecessors, was an aggregate spatial interaction based model that represented the relationship between transport cost and the spatial distribution of activity locations and concerned entities. Towards the latter half of 1980s, Rho and Kim (1989) came up with a non-linear urban equilibrium model that was based on export requirements of urban goods, cost minimization, entropy maximization of commodity flow, transportation network equilibrium and spatial price equilibrium.

Growing urbanization trends in the last decade of twentieth century in East Asian cities also forced the urban modelers to come up with ILUT models that could address the problems associated with urban planning. Miyamoto and Kitazume (1989); Miyamoto and Udomsri (1996) proposed a random utility based model RURBAN - developed at Tohoku University in Sendai, Japan - that was based on the principles of random utility and bid rent location. Bid rent approach follows a theory in which

companies choose such location where the bid rent equals the market rent (Alonso et al., 1964). Bid rent is the price at which the companies' profits are maximized (De Palma et al., 2011). The model assumes that the equilibrium in land market is reached when the land demand obtained from random utility theory and the land supply, derived from rent bidding become equal (De Palma et al., 2011). The model has been applied to metropolitan areas of Sapporo and Sendai in Japan as well as to Bangkok in Thailand (De Palma et al., 2011). A similar bid-rent location model was developed for Santiago, Chile by Martinez (1996). The 5-stage Land-Use Transport Model, abbreviated as MUSSA is linked with the traditional 4-step transport model ESTRAUS. ESTRAUS yields the economic accessibility indices which are used by MUSSA to provide the location of activities. Another notable aggregate-based discrete choice utility ILUT model was conceived by Still and Simmonds (1997), known as DELTA/START. The START transport model, designed to include all the major components of a transport strategy, provides the accessibility and environmental impacts to the land use model, DELTA. DELTA in turn provides the land use inputs such as population and employment changes, household and population relocation, changes in the job market etc. to START in a two-way feedback system.

The end of the twentieth century saw a shift in the trend of ILUT modeling. The transport authorities around the world felt the need of more rigorous and robust mechanism to better express the land use - transportation nexus. The more prevailing aggregate approaches were unable to cater for the individuality inherent in travel experiences. Therefore, microscopic modeling focusing on the behavior of individuals of the household gained more relevance at the turn of the century.

2.1.2 Microscopic ILUT Modeling

Popularized in last couple of decades, microscopic ILUT modeling involves disaggregation of land use and transport data to the level of individual member of the household. Microsimulation is useful for the situations where personalized decision making is involved (Miller and Salvini, 1998). Such type of microsimulation better represents the reality since household try to optimize their housing needs considering the spatial and travel needs of all the members of the households and not just of a single member. The more prevalent aggregate approaches are found wanting when it comes to addressing individual travel needs and experiences (Moeckel and Nagel, 2016).

As stated above, microscopic model integration better reflects the individual travel behavior. It allows the land use model to query the transport model for all the individuals in a household. For example, If the need arises for a housing shift, the relocation will be, amongst other constraints, partly based on calculation of travel time, by all the available modes of transportation, to work for all the members and then subsequent feeding of that information into the land use model. This sound integration of travel demand and land use requirements offers a realistic picture of housing location decisions, modal choice and route choice (Moeckel and Nagel, 2016, p. 78).

Towards the end of the twentieth century, CUFM (California Urban Futures Model) - developed for the first time in 1992, was considered the pioneer in the

field of micro-simulation. It was also one of the earliest adopters of modeling the behavior of land developers who shape the future of the metropolitan growth. The CUF model incorporates the econometric projections, developable land units and land use changes. Logit models are used to model the discrete choice (Landis and Zhang, 1998).

UrbanSim, ILUMASS, ILUTE (Waddell, 2002; Miller and Salvini, 1998; Strauch et al., 2003) are other prominent examples of microscopic ILUT models developed in the last couple of decades (detailed overview of these three models is provided in the section below). These models have found extensive application throughout the world and enjoy considerable popularity amongst the transport authorities.

2.2 Overview of operational Microscopic Integrated Land Use and Transport Models

As stated in the previous section, microscopic ILUT models had gained prominence amongst government agencies responsible for sustainable urban planning of the metropolitan cities at the turn of the century. This section includes a brief description of three such microscopic integrated land use and transportation models to provide a conceptual understanding of how such models work.

2.2.1 Integrated Land Use Modeling and Transportation System Simulation - ILUMASS

The ILUMASS combines the interaction of land use, transport and environment, developed at a microscopic level. The two-way feedback system consists of accessibilities to the locations, provided by the transport model, in the region dictating the land use decisions of the households, offices and real state developers. The impact of travel activities and trips on the environment is fed back into land use side as well which also plays a significant role in housing relocations and suitability (Strauch et al., 2003, p. 2-5). The microscopic modules in the ILUMASS are described as:

- **Landuse Changes:** The land use model uses synthetic data which itself is derived from accessible public data. The input data includes synthetic data related to households, housing units, car ownership, non-residential buildings, firms, workers as well as transport network related data including roads and public transportation. The land use data entities undergo change during every simulation run owing to events of choices, policies and selections. Those events include, but not restricted to, moving to a new house, marriage, child birth, divorce, change of workplace, addition of new dwellings, renovation of old dwellings, creation of new jobs etc. (Strauch et al., 2003, p. 7-8).
- **Travel Demand and Activity Patterns:** The activity generation model within the land use side, develops time-bound O-D matrices. To capture the activity behavior of the individuals, a computerized hand-held survey instrument is utilized. The EX-ACT survey was developed keeping in mind the scheduling behavior of the individuals. 402 individuals took part in the survey

that was conducted in the study area of ILUMASS, the city of Dortmund from November 2002 to February 2003. Personal Digital Assistants or PDA's were employed to record the individual activity repertoire and subsequent activity scheduling. The different stages of EX-ACT included a pre-interview to capture socio-demographic characteristics of household and its members, insight about individual trip planning, a weekly trip diary and post interview to gauge the suitability of the software and hardware (Strauch et al., 2003, p. 8-12).

- **Traffic Flow:** The traffic flow model uses the travel time O-D matrices forecasted by the activity generation model. It provides the connection between transport network and activity patterns. The planned trips are under-taken and the practicality of the trips is established. The iterative nature of the model allows the rescheduling of the plans until an equilibrium is established rendering all plans feasible (Strauch et al., 2003, p. 12).
- **Environmental Impacts:** The environment component of ILUMASS records the environmental impact of traffic and influences land use development decisions (Strauch et al., 2003, p. 12).
- **Urban Goods Transport:** For modeling urban good transport, a simplified urban goods transport model was developed (Strauch et al., 2003, p. 12).

The integration of all the sub- modules is achieved by a control algorithm that involves integration of each of the sub modules in a common and standardized operating system. The input and output data files will achieve the communication within the program system (Strauch et al., 2003, p. 13).

ILUMASS, at the time of its creation in 2003, was one of the first integrated land use and transport model in Europe that went a long way toward opening new research avenues for the development of further ILUT models, applicable for the European scenarios (Strauch et al., 2003, p. 14).

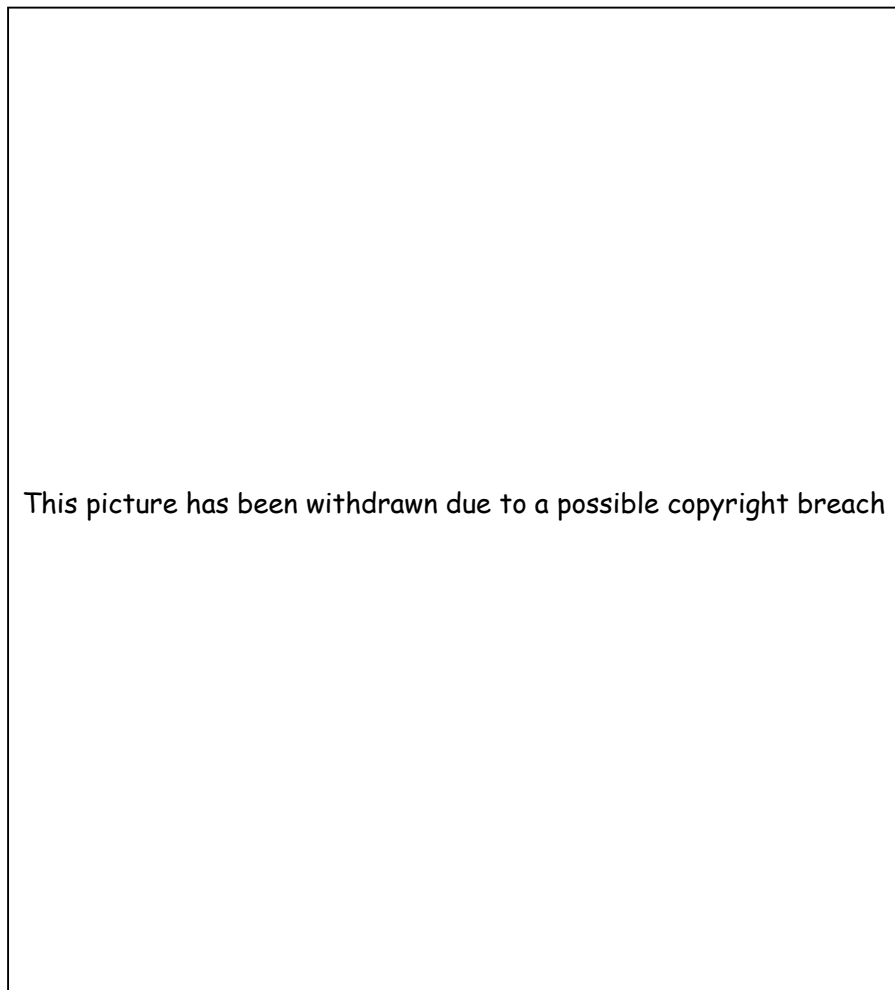


Figure 2.1: The ILUMASS Model (Strauch et al., 2003)

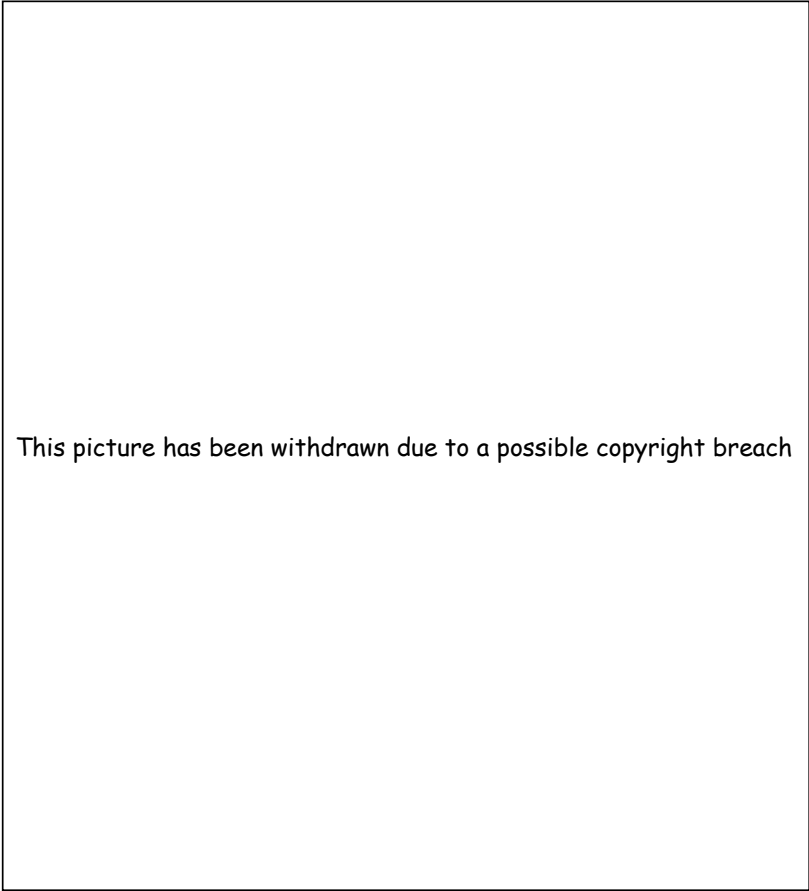
2.2.2 Integrated Land Use, Transport and Environment Model - ILUTE

Developed by a joint venture of four Canadian universities in late 1990s, ILUTE is a fully microsimulation based model with individual households and firms being the basic building block (Miller and Salvini, 1998, p. 5). The broader components of the system are: 1) Land development which deals with the evolution of the land use system, 2) Location choice involving location choice of households, firms and workers, 3) Activity Behavior catering for the trip making tendencies of the individuals and 4) Auto-ownership which models the private car ownership of the households (Miller and Salvini, 1998, p.3).

Brief description of the components of ILUTE is given below:

- **Population Synthesis:** This component involves the creation of a synthesis population from an aggregate data. The synthetic population serves as base population for the long run microsimulation (Miller and Salvini, 1998, p. 6).
- **Population Dynamics:** The dynamics of an urban are evolving all the time. People age over time, marriages happen, births occur, people relocate, people move out, jobs are switched, new housing units are created, old dwellings are demolished, new firms are formed, new jobs are created. All such dynamic changes are catered by the evolutionary engine of the ILUTE model. The researches enjoy varying degree of elasticity in choosing the complexity used to model the urban evolution (Miller and Salvini, 1998, p. 7).
- **Decision-Making Behavior:** To cater for the inherent complex nature of decision-making, since not all decisions are taken at the individual level - some situations might involve multiple persons, the ILUTE team came up with the concept of decision-making unit. It is the behavioral representation of person or persons making a decision (Miller and Salvini, 1998, p. 8).
- **Time Scale:** The model involves short term activity based travel demand microsimulation within a long-term land use evolution. Typically, the travel behavior of a single weekday is assigned and realized on the transport network. The travel time and emissions are calculated which are then fed into the land use component which runs on an annual basis. The travel patterns and costs would be considered while making long term decisions like housing relocation, automobile ownership, work location etc. (Miller and Salvini, 1998, p. 9).

Written in C++ with approximately 15000 lines and around 50 classes, the ILUTE model is based on object - oriented systems in which every entity of the whole system is treated as an object that interacts with one another (Salvini and Miller, 2005, p. 2). In a land use - transport model like ILUTE, these objects are people, firms, dwellings, workers etc. Such system allows for the modeling and programming of the behavior which is at the core of ILUT modeling (Miller and Salvini, 1998, p. 12).



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Figure 2.2: Overview of ILUTE Model (Miller and Salvini, 1998)

2.2.3 MatSim and UrbanSim

This interactive microscopic ILUT model involves combining agent based, disaggregated transport model, MatSim, with a metropolitan scale disaggregated land use model, UrbanSim. The brief description of UrbanSim is given below while that of MatSim would be provided in the following chapter.

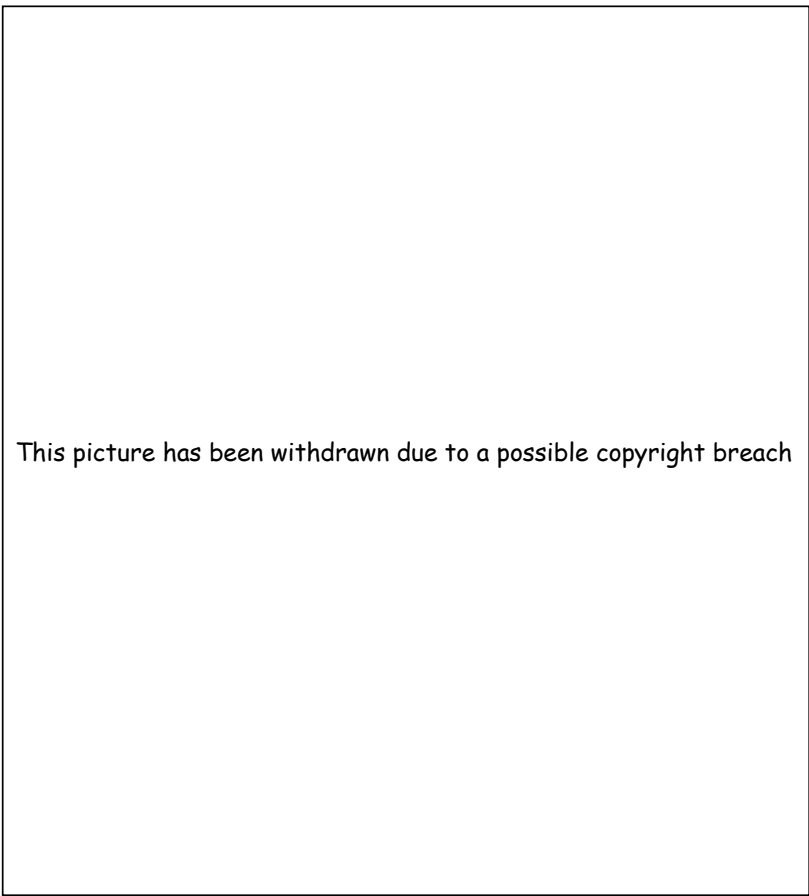
UrbanSim is an open source, metropolitan scale land use model which is integrated with transportation models to study the interaction of land use and transportation at a microscopic level. The model was developed to address the policy requirements of metropolitan growth with land use and transportation interactions taking the center stage (Waddell, 2002, p. 298). An open source software, it is available publicly for usage, editing, modification and redistribution without any cost. Two key inputs treated as exogenous by UrbanSim are a) macroeconomic model which predicts the macroeconomic development of the population and employment and b) a travel demand model system which forecasts the travel conditions. The travel demand model is loosely integrated with UrbanSim in a two-way feedback

system; the land use predictions acting as input for the travel demand model while travel conditions acting as input for the UrbanSim land use model (Waddell et al., 2003, p. 5).

Main modules within UrbanSim are summarized below:

- **Accessibility Model:** The accessibility model generates the accessibility indices to the destination from each zone which is to be used in the household and business location model (described below) (Waddell et al., 2003, p. 7).
- **Demographic and Economic Transition Model:** : The demographic evolution such as births and deaths in the population of households are simulated in the demographic transition model. Iterative proportional fitting, proposed by Beckman et.al in 1996, is used to determine how many households of each type are supposed to be created and deleted. The changes in the job market like job creation and job losses are simulated in economic transition model (Waddell, 2002, p. 306).
- **Household and Employment Mobility Models:** The probability of moving of a household from its current location are calculated from the historic data. Once the household decides to move, it is considered as being inactive and the its formerly occupied place is rendered available (Waddell, 2002; Waddell et al., 2003). The employment mobility model uses the same concept as household mobility model and estimates which jobs will move to a new place during a particular year from their current location (Waddell, 2002, p. 306).
- **Household and Employment Location Models:** The location models are based on the prediction of new location for a household and a job that currently has no place. Multinomial logit models are used to calculate the suitability of the most desired location for the household and job, amongst a sample of locations randomly selected from all available vacant alternatives (Waddell, 2002, p. 306)(Waddell et al., 2003, p. 11-15).
- **Real Estate Development Model:** The real estate development decisions by the developers are simulated in this particular model. The model performs iteration on all the grid cell (150 meter; unit of analysis for location and development) where development is possible and forms a list of all the possible development alternatives. Using multinomial logit models, the probability to choose an alternative is calculated. Some of the variables included in the model include characteristics of the grid cell, characteristics of the site location and regional accessibility to population (Waddell, 2002, p. 306).
- **Land Price Model:** The simulation of land prices of each grid cell is done in Land Price Model. Hedonic regression is used to calibrate the model from historical data to include the effect of site, neighborhood, proximity to highways and policy changes on land price (Waddell, 2002, p. 306; Waddell et al., 2003, p. 19).

An output module is responsible for writing the results of the simulation to the user-specified formats for further analysis (Waddell, 2002, p. 308) . The model



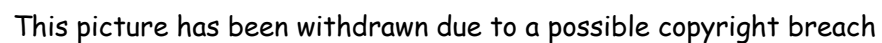
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Figure 2.3: UrbanSim Workflow - (t.1...t.7 represent the sequence of operation during one simulation run) (Waddell, 2002, p. 305)

system has already been applied to three metropolitan areas of U.S and is being further improved to address the shortcomings and suggestions from end-users and researchers (Waddell et al., 2003, p. 21).

Integration of MatSim with UrbanSim

During the yearly iteration of UrbanSim, MatSim is called once per year and is passed a path to traffic network data alongwith household and work locations data as input. Using this input, MatSim runs the traffic assignment within itself and produces the accessibility indictors which are then passed on to UrbanSim. For the next yearly iteration in UrbanSim, the updated data from MatSim is used by Household and Employment Location Model as well as Land Price Model (Nicolai and Nagel, 2015, p. 10).



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Figure 2.4: Workflow between UrbanSim and MATSim
(Nicolai and Nagel, 2015)

Chapter 3

Model Description

In this chapter the model used to assess the LUTI impacts is described. First a brief overview of available technologies is given.

3.1 Selection of the Model

The model chosen to evaluate the impacts of second Stammstrecke on land use and transport flows of Munich Metropolitan Area is an ILUT model, SILO-MATSim, developed by the Assistant Professorship of Modelling Spatial Mobility at TUM, Munich (Assistant Professorship of Modeling Spatial Mobility, 2018a).

The model has been chosen for this thesis owing to the availability of it, and thus does not claim to be the best operational model from the integrated land-use and transport model. In the section below, the characteristics and dynamics of the ILUT model chosen would be described to argue the general suitability of the model and deeming it as being a congruous tool for the later scenario analysis.

3.2 ILUT Model SILO-MatSim

The state-of-the-art integrated land use and transport modeling suite has been developed and is being gradually applied to the Munich Metropolitan Area. The ILUT model in question is distinctive in the sense that it is one of the very few microscopic ILUT models that is comparatively simple to apply to various study areas and policy situations (Moeckel and Nagel, 2016, p. 74). Historically, various models developed to address the LUTI have been rather too complex and tedious to implement to a real-world scenarios and projects (Wagner and Wegener, 2007; Moeckel and Nagel, 2016) . Some of the operational ILUT models have experienced considerable difficulty in linking the land use model with the transport model owing to software integration issues in case of ILUMASS (Wagner and Wegener, 2007), and programming language differences in land use and transport models in case of UrbanSim-MatSim (Nicolai and Nagel, 2015; Moeckel and Nagel, 2016).

Written in common programming language, JAVA, SILO-MatSim integration takes care of uncommon programming platform issue.

3.2.1 SILO

Initially developed by Rolf Moeckel, while working at Parsons Brinckerhoff, Inc. for Minneapolis/St. Paul in Minnesota, USA, this land-use model is a disaggregated one that facilitates the integration with any travel demand model. The inherent characteristics of SILO are based on microscopic treatment of all the land use objects (household, person and dwellings) as well using discrete choice modeling to precisely explain the relocation decisions of the objects (Silo.zone, 2018a; Assistant Professorship of Modeling Spatial Mobility, 2018b).

The decision modeling in SILO is based on Logit models and Markov models. All the decisions related to relocation of households, firms, new dwellings constructions etc are modeled by employing Logit models while the decisions like marriage, birth, moving out of a household, renovation of dwellings use Markov models.

The SILO is made up of several modules that individually model all the land use related data. The modules are concisely explained below:

- **Synthetic Population:** The population data is synthesized to represent the actual population. The statistical data is derived from GENESIS-Online Database and the 2011 Household Census (Silo.zone, 2018d). The synthetic data is generated using various procedures and is executed once in the base year. The module generates lists of households, person, dwellings and jobs. The lists are updated every year with every simulation run (Silo.zone, 2018b).
- **Demographic Evolution:** The changes in the household are simulated by the demographic module. The changes include getting married, giving birth, deaths, divorces, aging, moving out of the household, workers opting for newer jobs etc. The changes are simulated randomly to better represent the reality using the synthetic data (Silo.zone, 2018b).
- **Household Relocation:** The household opting to move to a new place is taken care by household relocation module. The household relocation is affected by the demographic evolution. The household weighs the new housing against its current housing and decide to move if the new housing has more attractive attributes (Silo.zone, 2018b).
- **Real Estate Development:** All the land development changes like construction, renovation, deterioration, destruction etc. are modeled by the developer model. The new dwellings are built by the developers if the demand for the housing is high. Similarly, some dwellings are demolished based on the rating of the quality of the dwelling (Moeckel and Nagel, 2016; Silo.zone, 2018c).
- **Employment:** The changes associated to the work and jobs are catered by the employment module. Currently, SILO uses the zonal employment forecast data for the base year as well as final year and the data for all the intermediate years is obtained using interpolation. The zones having abundance of jobs are deprived from some of the jobs in the next simulation period while the jobs are created for the zones having deficiency of jobs (Silo.zone, 2018b).

3.2.2 MATSim

MATSim is an agent based, transportation model that simulates the travel demand decisions based on individual choices. First developed by Horni et al. (2016), MatSim typically models the individual activity behavior over the course of one day.

MATSim uses co-evolutionary algorithm, executed in a form of loop, to gradually reach towards the most optimized daily activity schedule (Horni et al., 2016, p.4). Every agent begins its day leaving from a particular activity location and moves to one activity location after another, performing various activities, until the day is over (Moeckel and Nagel, 2016, p. 75). This daily activity pattern is called mobility simulation or *mosbim*. A typical iteration starts with every agent picking a plan from a list of plans, stored in its memory. With the execution of all the plans, plan with the best score is chosen after every mobsim run. Following every iteration, the agent revises and later can add new plans to its memory. Towards the end of the iteration, plan with the best score is adopted which, in other words, is the most suitable and optimized one (Horni et al., 2016, p. 5; Moeckel and Nagel, 2016, p. 75).

Figure 3.1: MATSim Cycle (Horni et al., 2016, p. 4)

3.2.3 Integration of SILO and MATSim

Every simulation of SILO begins with reading base year data and then all the sub-modules account for all the land use changes in the given year using the synthetic population data. SILO then provides the MATSim with all the location changes which are taken into account during the execution. MATSim then provides SILO with updated travel characteristics. Thus a two way feedback cycle is established that allows both the land use and transport model to query each other for the updated data at a microscopic level (Moeckel and Nagel, 2016, p. 74).

Figure 3.2: Interaction of SILO with MATSim (Moeckel and Nagel, 2016, p. 78)

Chapter 4

Model Specifications and Implementation

4.1 Model Timeline

The SILO-MATSim model implementation for Munich Metropolitan Area starts from year 2011 and lasts till 2050. Therefore, the study period for this research thesis also encompasses this time period. The scenario analysis mainly focuses on the year when the 2nd Stammstrecke opens i-e 2026 and then on the expected impacts once the infrastructural change would fully settle down and give realistic patterns for LUTI which is year 2050.

SILO runs annually from 2011 till 2050 while the transport model is picked to run in 2012, 2026 and 2050. The maiden simulation utilizes the existing transport network. For the second simulation, the transport model run for the year 2012 employs the existing private and public transport networks while for the year 2026 and 2050, the public transport network changes (explained later in the section) owing to the second Stammstrecke are incorporated. The third simulation involves an input change in SILO at the start of year 2026 when housing units are added exogenously as part of the third scenario (explained in the following section). The transport model inputs remain the same like that of second simulation.

The scaling factor for the transport model runs in MATSim is chosen to be 5 percent for reducing the duration of the simulation. This means that only 5 percent of the total agents will be simulated in the transport model. The number of iterations are set to be 50 for a complete MATSim run. Moreover, the focus of this research is on the commute trips taking place in the study area and hence only home-based work trips are considered for analysis. Since the proposed 2SS project aims to strengthen the transit part of overall modal share, therefore only private trips made by car, apart from public transport trips, are considered. All other modes of transportation are neglected to better collate the modal changes across the study period.

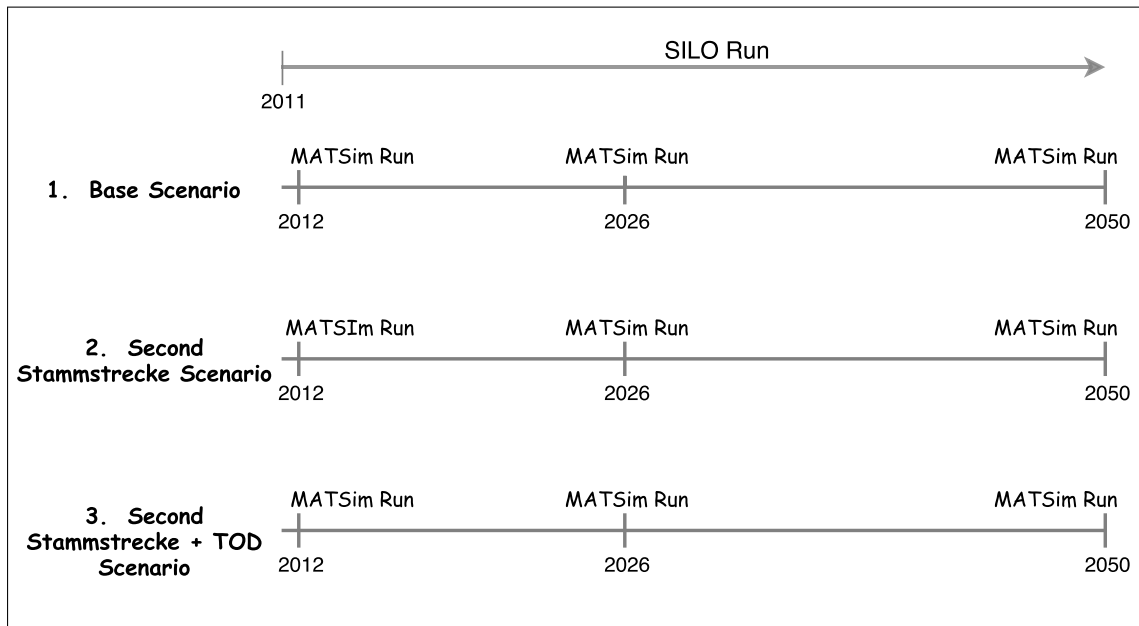


Figure 4.1: Overview of the SILO-MATSim running timeline

4.2 Study Area

The study area for the thesis research, shown in Figure 4.2, is Munich metropolitan area comprising of major urban centers of the region, namely Munich, Augsburg, Inglostadt, Landshut and Rosenheim. The model is already being applied to the Munich metropolitan area and hence it is decided that the same boundaries should also be kept for the scenario analysis in this thesis research to facilitate easier and convenient implementation of the model for the proposed scenarios.

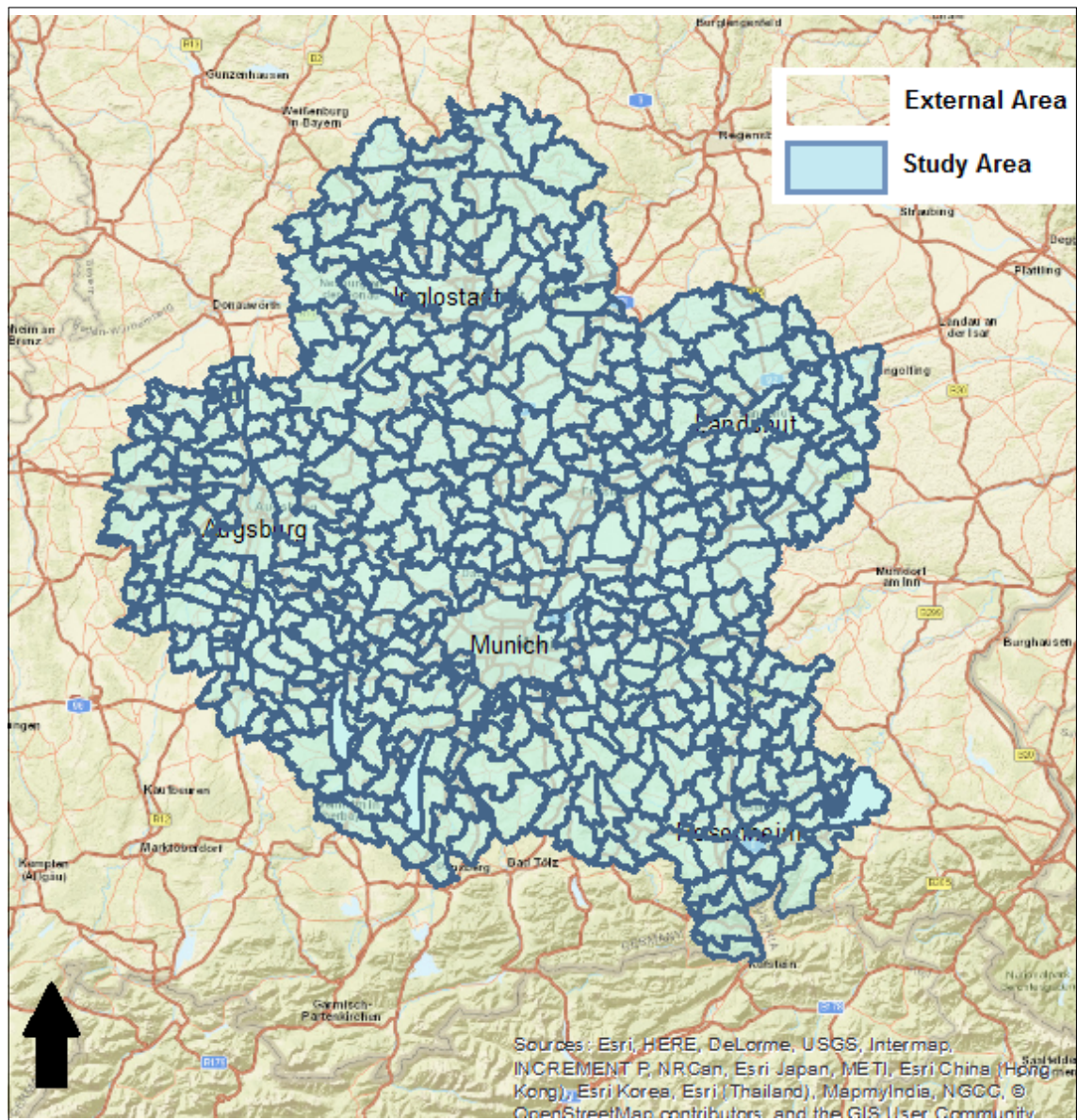


Figure 4.2: The Study Area

4.3 Scenario Development

The model implementation involves development of two scenarios and their subsequent analysis and comparison.

4.3.1 Base Scenario

The first scenario is the fundamental one in any scenario analysis project - Do nothing. This scenario assumes that there is no infrastructure change in the MMA transportation network and all the regional trains, S-bahn, U-bahn, tram and bus lines will undergo no modification and upgradation. The private transport network which includes roads will also remain the same throughout the study period.

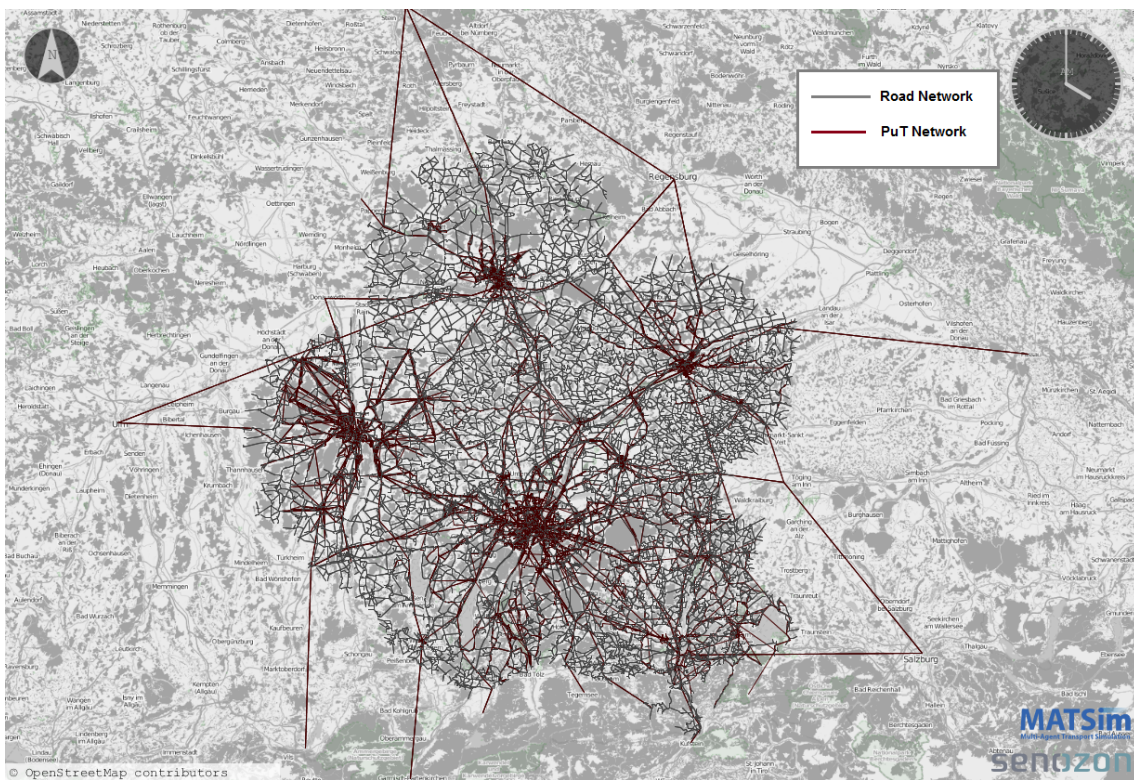


Figure 4.3: The existing transportation network - for Base Scenario

4.3.2 Scenario 1 - The 2nd Stammstrecke Scenario

The second scenario is what this thesis research basis around, the construction and implementation of the second express S-bahn line, called 2nd. Stammstrecke. This scenario will come into play from year 2026 onwards, since this is the year the 2nd Stammstrecke is scheduled to open. All the changes associated with a revamped S-bahn network are processed into the model.

4.3.3 Scenario 2 - The 2nd Stammstrecke plus Transit Oriented Development

In order to better compare the results with base scenario and to see if the proposed infrastructural development of second express line would reap more benefits, a third scenario is proposed where the additional housing would be developed in the year the second Stammstrecke opens i-e in 2026. 1000 housing units would be added in each of the zones where the express line stops are located. An average rent for all the housing units is chosen based on the existing average rent in each of the zones where those housing units are going to be added.

4.4 Data Preparation for MATSim Model

The MATSim model is already functional for the existing transportation network of the study area. In order to implement the Scenario 2, the transit network data has been edited and updated which later is implemented in the model.

4.4.1 Existing Transport Network in MMA

Current MATSim model run is based on existing transit network of Munich Metropolitan Area. The network consists of all the public transportation lines, the location of the stops, and the schedule of all the lines as they are represented by the MVV network map.

As shown by Figure 4.4, the current transportation network comprises of eight S-bahn lines and six regular U-bahn lines. Out of total of 8 S-bahn lines, 7 regular lines use the current Stammstrecke (for reference convenience, it would be referred to as 1st Stammstrecke in future citings in this study), which runs from Pasing in the west to Munich Ostbahnhof to the east. The S-bahn lines cover all the surrounding districts of Munich and serve the MMA with a headway of 20 minutes. During the peak hour period, an S-bahn departs every two minutes through the 1st Stammstrecke (2.Stammstrecke Muenchen, 2017b).

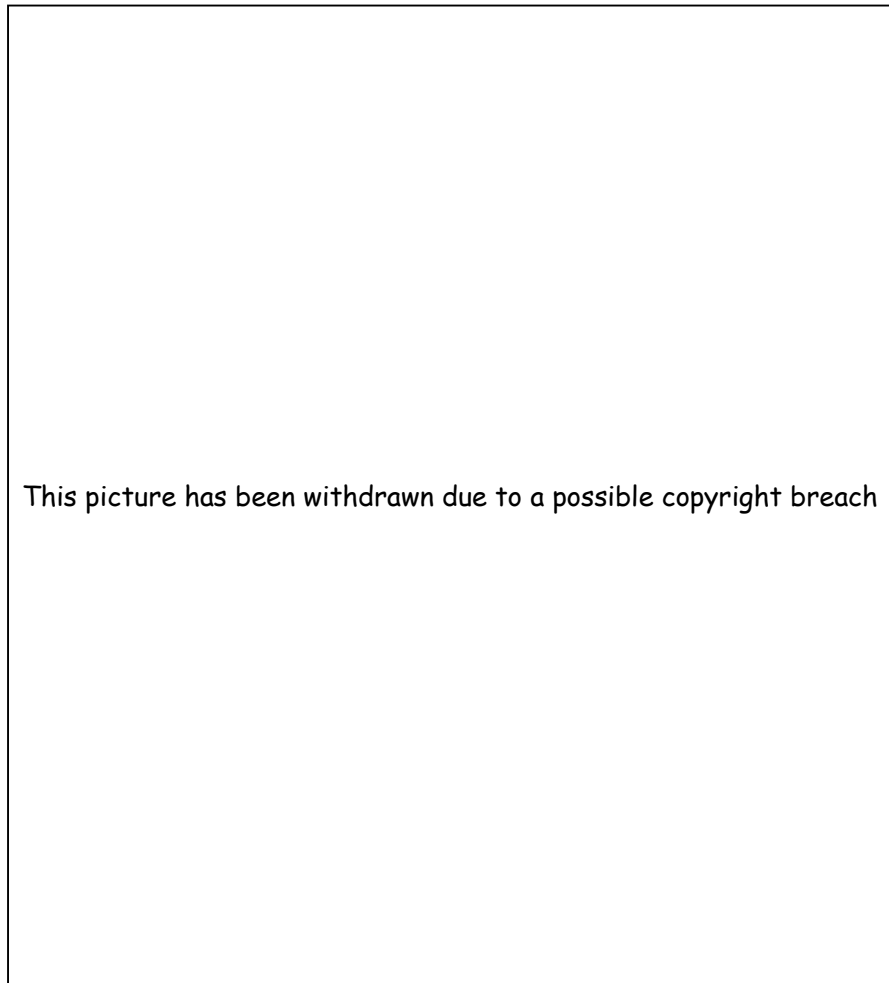


Figure 4.4: Existing Public Transportation Network (MVV-muenchen.de, 2018)

4.4.2 The 2nd Stammstrecke

The planning authorities have already proposed a new S-bahn line network once the 2nd Stammstrecke project becomes functional in 2026. Therefore, following that new transportation network map of MMA, the changes to the existing lines, stops and schedules have to be made in order to input the data that would reflect the transportation network situation in 2026.

Evident from Figure 4.5, part of the S-bahn network will undergo major revamping with the introduction of the second main line. The central station (*Hauptbahnhof*)(Hbf), *Mareinhof*, *Ostbahnhof* and *Leuchtnberggring* will take central stage with all the existing and new lines going through these three stations.

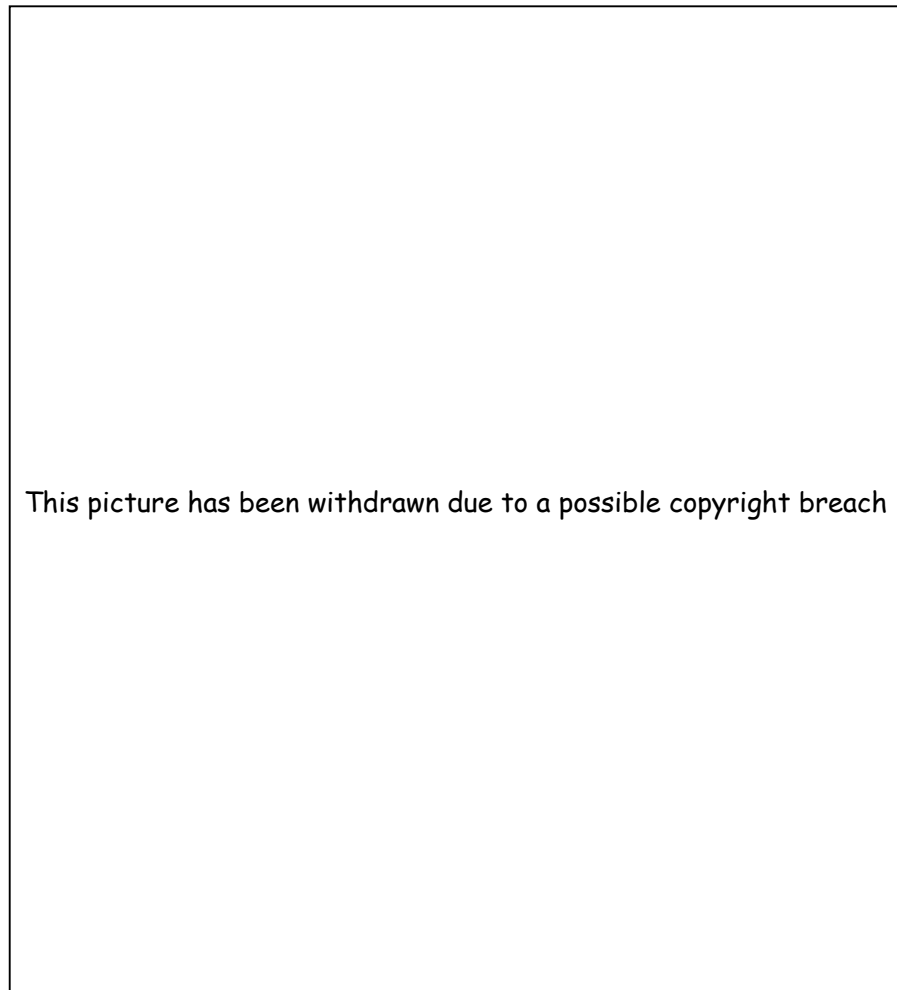


Figure 4.5: The Proposed Line Network after 2nd Stammstrecke, as of April 2017 (2.Stammstrecke Muenchen, 2017a)

Express Lines

Four express lines S21x, S18x, S23x and S24x would be the new addition to the current network. A brief description of the route of those lines is described below:

- **S21x** will follow the direction of S1 and would connect Landshut with the Munich central area. Along the way, it would serve the districts of *Gündlkofen*, *Bruckberg*, *Moosburg*, *Langenbach* and *Marzling* before stopping at *Freising*. From there onwards, it will follow the S1 route but will stop at limited stops only before entering the 2nd Stammstrecke at *Laim* and finishing at *Leuchtenbergring*.

- **S23x** will connect the Northwest region of MMA with the Munich Airport. Starting at *Mering* in Northwest, it will join the S3 at *Maisach* while connecting the districts of *Althegnenberg*, *Haspelmoor*, *Mammendorf* and *Malching* on the way. From *Maisach*, it will mimic the S3 route but only stopping at a couple of stops before stopping at *Pasing*. Serving the 2nd Stammstrecke stops, barring *Leuchtenbergring*, it will follow the S8 route without stopping at any station till *Flughafen Besucherpark*. The *Flughafen München* (Munich Airport) marks the terminal stop of S23x.
- **S18x** will begin from Southwest region of the study area at *Herrsching*. It will follow the S8 route and along the way, it will serve only four existing stops of S8 before entering *Pasing*. From *Pasing* it will enter the 2nd Stammstrecke at *Laim* before ending at the west end of the new main line at *Leuchtenbergring*.
- Starting at the West edge of the MMA at *Buchloe*, the **S24x** will follow the S4 line route, stopping at *Geltendorf* and would then serve the region of *Fürstenfeldbruck*, *Puchheim* and *Pasing* before entering the 2nd Stammstrecke at *Laim*. It will then pass through the core stops of 2nd Stammstrecke and finish at *Leuchtenbergring*.

In addition to the four express lines, the regular lines S1 and S6 will also be shifted to the 2nd Stammstrecke thereby reducing the number of stops for both of these lines.

4.4.3 Modification of the Transit Network for MATSim

The modification of the transit data involves the changes to the data of all the transit lines, stops and schedule that had been prepared for the transport model of the MMA. The transit data adaptation has been done primarily by following the proposed transport network in 2026 (4.5). The refinement of the transit data is described below.

Changes to the Lines

The first part of the modification includes modifying all the lines and their supposed routes according to the Figure 4.5. Each line of the network is given a Line ID, Stop ID and a sequence of all the stops. The express lines of the 2nd Stammstrecke are given new and unique ID numbers that are not part of the existing database of Line IDs. Moreover the core stops of the 2nd Stammstrecke; *Hauptbahnhof*, *Marienhof* and *Ostbahnhof* are given new Stop IDs due to the assumption that these stops will be located at wide enough distance from the existing stops of *Hauptbahnhof*, *Marienplatz* and *Ostbahnhof* and therefore warrant a unique stop location in the transit network. Therefore, the new stops at *Hauptbahnhof*, *Marienhof* and *Ostbahnhof* are treated as separate stops in 2nd Stammstrecke analysis.

The new version of S6 line is presented in Figure 4.6. S6 will be shifted to the second Stammstrecke after completion. It will start from *Tutzing* and will enter the second Stammstrecke at *Laim*. It will then pass through the core 2SS stops before terminating at *Leuchtenbergring*.

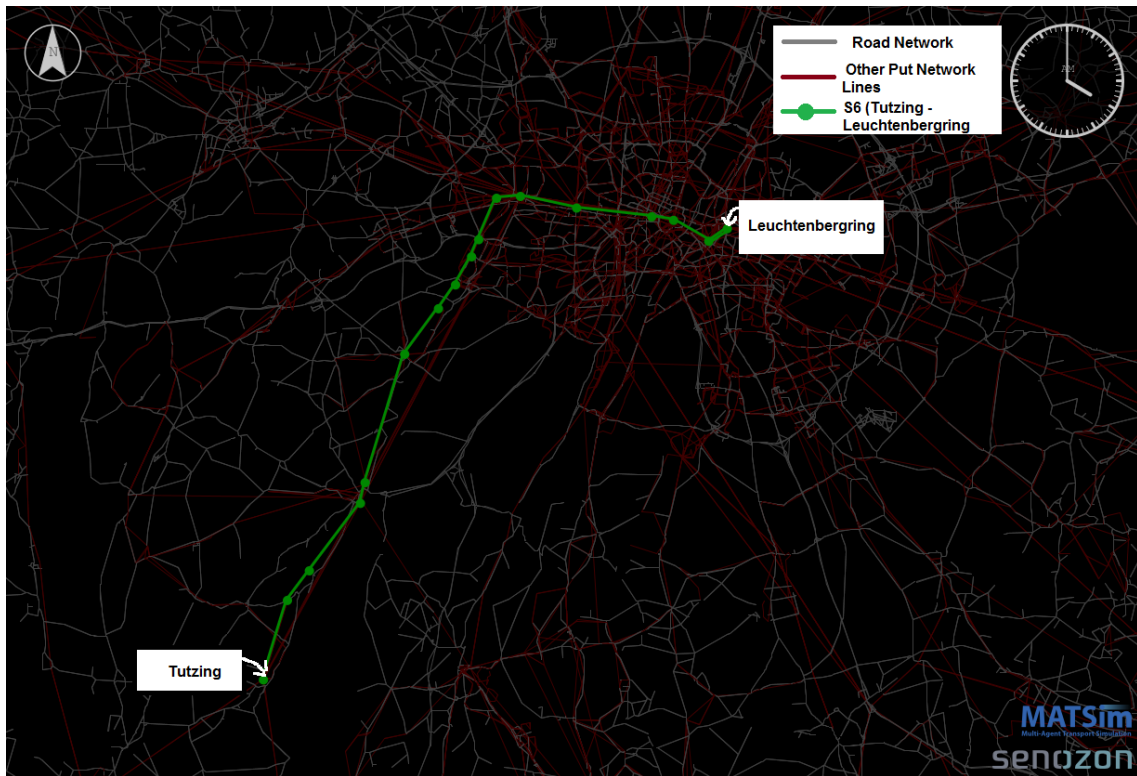


Figure 4.6: The revamped S6 line as part of 2nd Stammstrecke

Changes to the Stations

The 'Stations' file include the location of all the stations of the MMA. The latitude and longitude of all the stations mark the exact location of the transit stops. The new stations as well as the stations that were missing from the original file have been added. The latitude and longitude of the stations have been obtained from the Google Maps by marking a suitable location on the maps. Apart from the coordinates information, all the new stations have been given a unique Stop ID.

Changes to the Schedule

The major change of the transit data has been done to the 'Trips' or Schedule file of the transit network. Since there is no available information about the possible transit schedule of the S-bahn lines in the post 2nd Stammstrecke scenario, therefore suitable assumptions and subsequent calculations according to those assumptions have been done in order to calculate the schedule.

- **A headway of 20-minutes for regular lines and 30-minute headway for Express lines:** This is a conservative assumption of the post 2nd Stammstrecke operation of the network since the available information states that some of the regular lines will run with a 15-minute headway (2.Stammstrecke Muenchen, 2017a). Therefore the travel offer and subsequent mode selection would conservatively be affected by this assumption.

- **20-second dwelling time at each stop:** It has been reasonably assumed that dwelling time for the train at each stop would be 20 seconds. This dwelling time is represented by boarding and exiting of the passengers.
- **Travel time between stops:** The travel time between stops has been calculated by using the time provided by MVV time tables. Because of the fact that no such time table information exists for the 2nd Stammstrecke stops, the travel time for the existing network has been used in cases where there is no change in the line routing. For calculating travel times between the core stops of the 2nd Stammstrecke, the equations of motion have been utilized.

$$v_f = v_i + a \cdot t \quad (4.1)$$

$$S = v_i \cdot t + \frac{1}{2} a \cdot t^2 \quad (4.2)$$

$$2aS = v_f^2 - v_i^2 \quad (4.3)$$

where

v_i = initial velocity

v_f = final velocity

a = acceleration

t = travel time

S = distance

Suppositions about travel time calculation

Few assumptions have to be made in order to calculate the travel time between the stops. The acceleration and deceleration rates are assumed to be equal and constant for simplification and from literature, it is found out that the acceleration rate of a normal suburban train is assumed to be 1.3 ms^{-2} (Parkinson and Fisher, 1996, p. 31-32). Some other sources state the acceleration rates at around 1.0 ms^{-2} . Therefore, for the calculation in this study, a value of 1.15 ms^{-2} is chosen. Since the core of 2nd Stammstrecke involves the tunnel, therefore maximum operating speed chosen for calculations is 110 kmph (30.5 meter per second), unlike the existing maximum speed of S-bahn which is around 140 kmph (bombardier.com, 2018). The distance to each stop is calculated by following the tracks of current S-bahn lines on Google maps.

Using Figure 4.7 as the basis of distance calculation, the distances between all those stations where S-bahns are supposed to travel but had no travel time information, have been computed. With all the parameters of equations of linear motion known, the travel time calculations are completed.

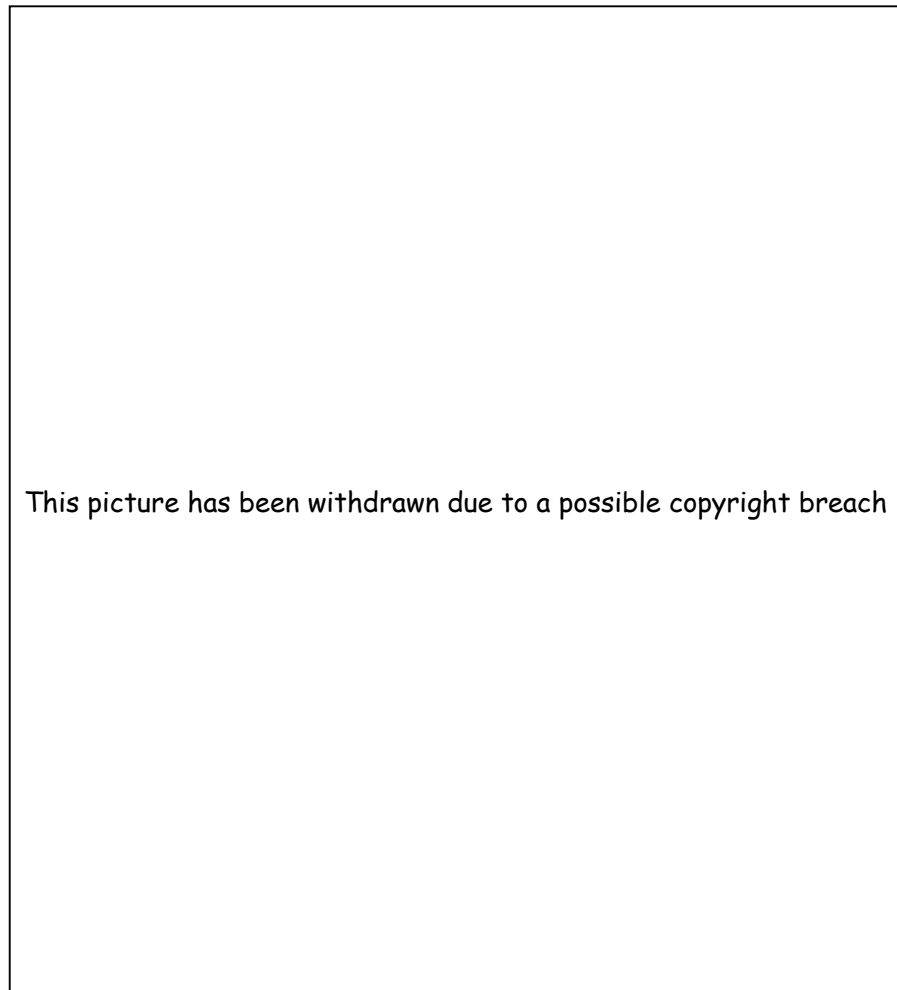


Figure 4.7: Distance Calculation between two 2nd Stammstrecke Stops (Laim to HBF) (maps.google.com, 2017)

Example Calculation of Travel Time between Laim to HBF

Speed = $v = 30.5 \text{ m/s}$

Initial velocity = $v_i = 0$

Final velocity = $v_f = 30.5 \text{ m/s}$

Acceleration and deceleration rate = $a = 1.15 \text{ m/s}^2$

Using equation (4.1):

Acceleration and deceleration time = $t_1 = t_2 = 30.5/1.15 = 26.5 \text{ s}$

Distance from Laim to HBF = $S_1 = 4270 \text{ m}$ (From Figure 4.7)

Using equation (4.2):

$$\begin{aligned} \text{Acceleration and deceleration distance} &= S_2 = S_3 = \frac{1}{2} \cdot 1.15 \cdot 26.5^2 \\ &= 403.8 \text{ m} \end{aligned}$$

$$\begin{aligned} \text{Time taken to complete remaining distance} &= t_3 = (S_1 - S_2 - S_3) / v \\ &= 3462 / 30.5 \\ &= 113.5 \text{ s} \end{aligned}$$

$$\text{Total travel time between Laim to HBF} = t_1 + t_2 + t_3 = 166.5 \text{ s}$$

4.4.4 Verification of Transit Data

Table 4.1: In transit travel time from a selected origin to selected destination

Origin Zone	Destination Zones	Zone name	Travel time (before)	Travel time (after)
Marienhof	-	-	minutes	minutes
3612	3781	Englschalking	13.2	8.4
3612	2291	Erding	20	28.7
3612	1617	Freising	25.7	27.2
3612	1158	Petershausen	33	29.7
3612	1061	Mering	32.3	39
3612	2424	Geltendorf	40.9	23
3612	3160	Herrsching	44.9	38.6
3612	4597	Holzkirchen	32.25	35
3612	4476	Aying	29.1	31.1
3612	4677	Grafring	16.4	17.6
3612	1659	Flughafen	33.3	24.3

In order to ensure that the input data for transit (S-Bahn lines schedule calculation based on travel time computations) is reasonable, a test run of MATSim is conducted which yields transit skim matrices. These transit skim matrices are function of zone-to-zone travel time which are later used by SILO to calculate the travel accessibilities.

The transit skim matrices for few of the selected zones that are going to be affected by eventual 2nd Stammstrecke are studied and travel time from origin to some of the destinations are compared for before and after 2SS scenarios. One such example of transit skim matrix showing in transit travel time from an origin zone (no. 3612) of study area (Marienhof) to multiple destination zones is given in Table 4.1.

A bar chart using the data from the Table 4.1 is shown below.

It is evident from Table 4.1 and Figure 4.8 that in vehicle travel time has undergone a reduction, which is plausible considering the fact that the 2nd Stammstrecke is supposed to enhance the travel quality, by skipping multiple stops, which would reduce the travel time in most cases. The ones suffering from an increase in the in

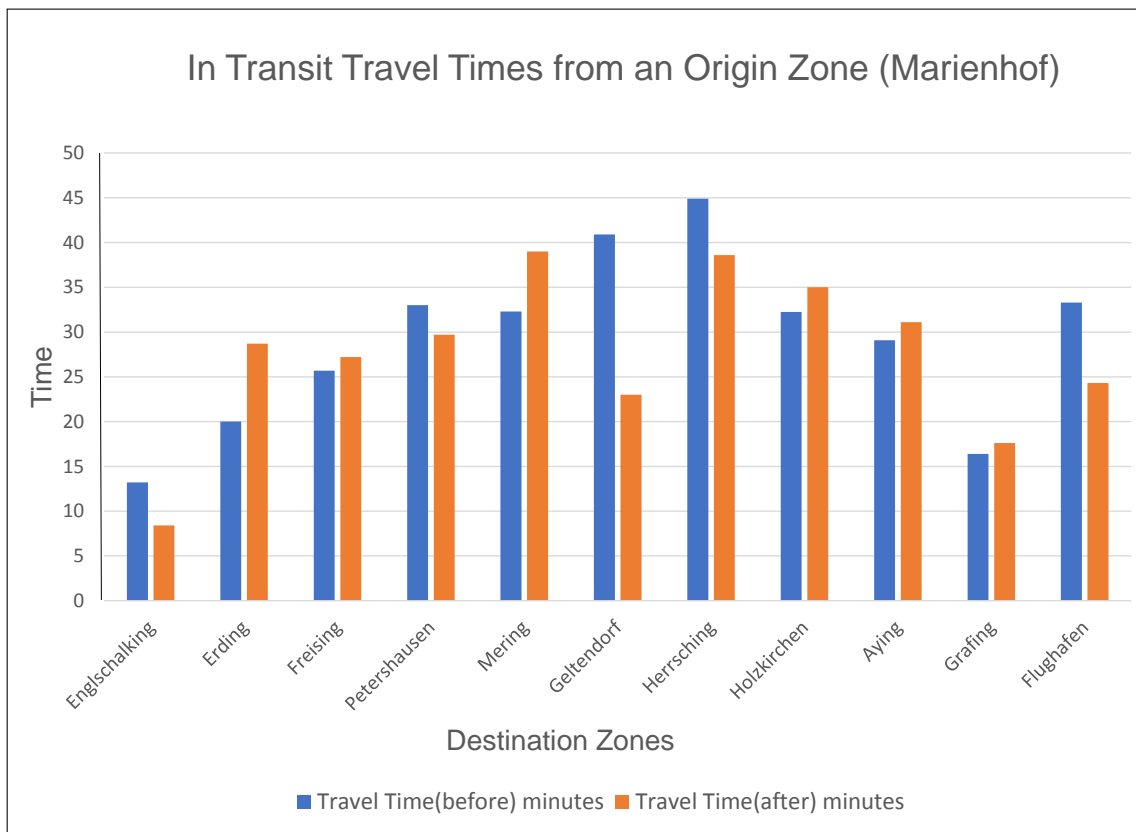


Figure 4.8: In Transit Travel time from Marienhof to chosen destinations going to be affected by 2SS

transit time indicate that those destinations might be worse off with the introduction of second express line and the subsequent revamping of the S-bahn network. However, the detailed analysis would be presented in the following chapter. At this point, it is assumed that the input transit data is reasonable and fit to be used in the SILO-MATSim model run.

4.5 Input Data for SILO

The SILO model is used in its running form for the MMA study area without performing any data modification. The normal data inputs, which were explained in the previous chapter, are provided to the model. One of the key developments for SILO is the microscopic zoning system of MMA study area. The complete region is divided into 4924 zones in such a way that the zones in denser areas are smaller in size compared to the sparser areas, where they are larger.

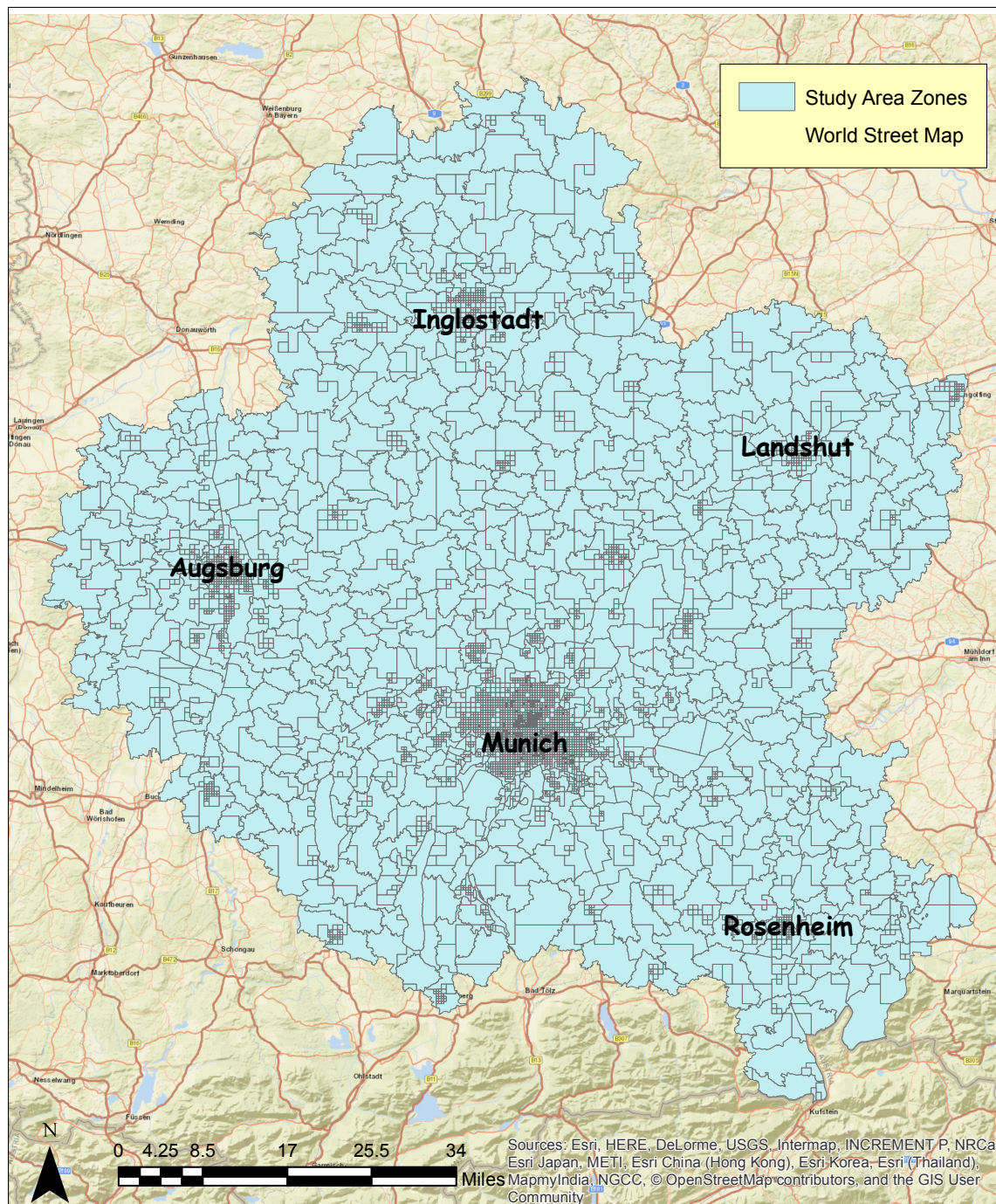


Figure 4.9: Zones of the Study Area

Chapter 5

Scenario Analysis

This chapter presents the analysis and the associated results of the three simulated runs of the modeling suite. The output data is visualized in the form of trends and tendencies of the various transport and land use parameters.

The parameters that are analyzed are:

- **Modal Split (Transit)**
- **Population**
- **Jobs**
- **Average Price**
- **Accessibility - Auto and Transit (overlooked in Municipality level of analysis)**
- **Car Ownership (at Munich Metropolitan Area)**

All these parameters are evaluated at different levels of analysis. These levels are:

- **Munich Metropolitan Area** - to see the impacts at the largest scale.
- **Express Line Municipalities** - to assess the impacts at the medium scale in the districts that are going to be served by the express lines 4.4.2 as part of the second Stammstrecke project.
- **Express Line Zones** - to gauge the impacts at the smallest scale of analysis in the individual zones, going to be served by the the express lines.

All the parameters will be assessed for the Base scenario(4.3.1) as well as the Scenario 1(4.3.2). Due to time constraint, only a few of the parameters at selected scales of analysis are assessed for the second Stammstrecke plus TOD scenario(4.3.3).

5.1 Modal Split(Transit)

The major evaluation parameter of the transport part of the model is the changes in the modal share of the public transportation over the course of the study period. The 2SS project will increase the capacity of the system hence it is relevant to see whether or not the ridership levels are positively affected.

MMA level

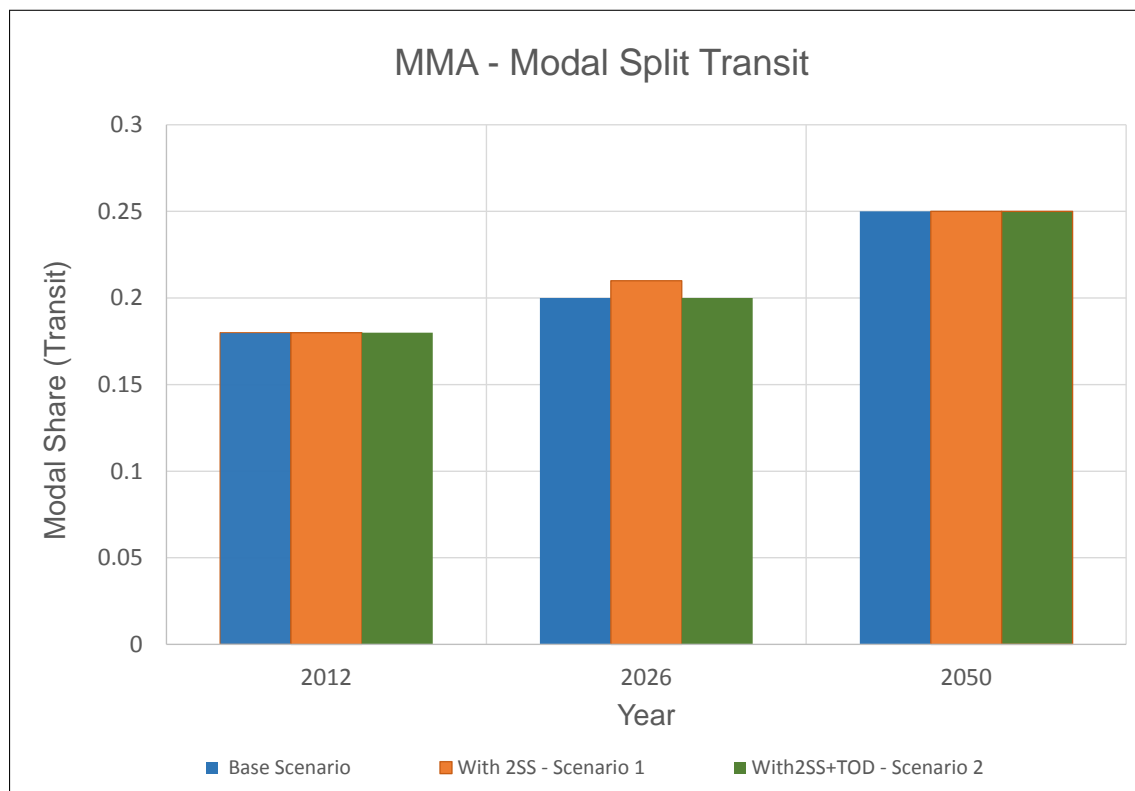


Figure 5.1: Modal Split at MMA Level

The modal share is calculated for the years 2012, 2026 and 2050, owing to the limitation of transport model run at the aforementioned years only. On a broader look, it is deduced that there is no significant change in the modal split situation for all the three scenarios in the MMA. There is a very slight upward shift in the transit share in the scenario 1 which is somewhat understandable as this is the year the second Stammstrecke opens, attracting a short chunk of drivers to use the public transport for commuting. One change which is consistent throughout the three scenarios is the gradual increase in the transit share in the three studied years. In the year 2050, one quarter of the total trips in MMA would take place by transit. However, the same modal split values for all three scenarios categorically indicates that the second Stammstrecke is going to have no real impact on the modal share at the MMA level.

Municipality level - Express Lines

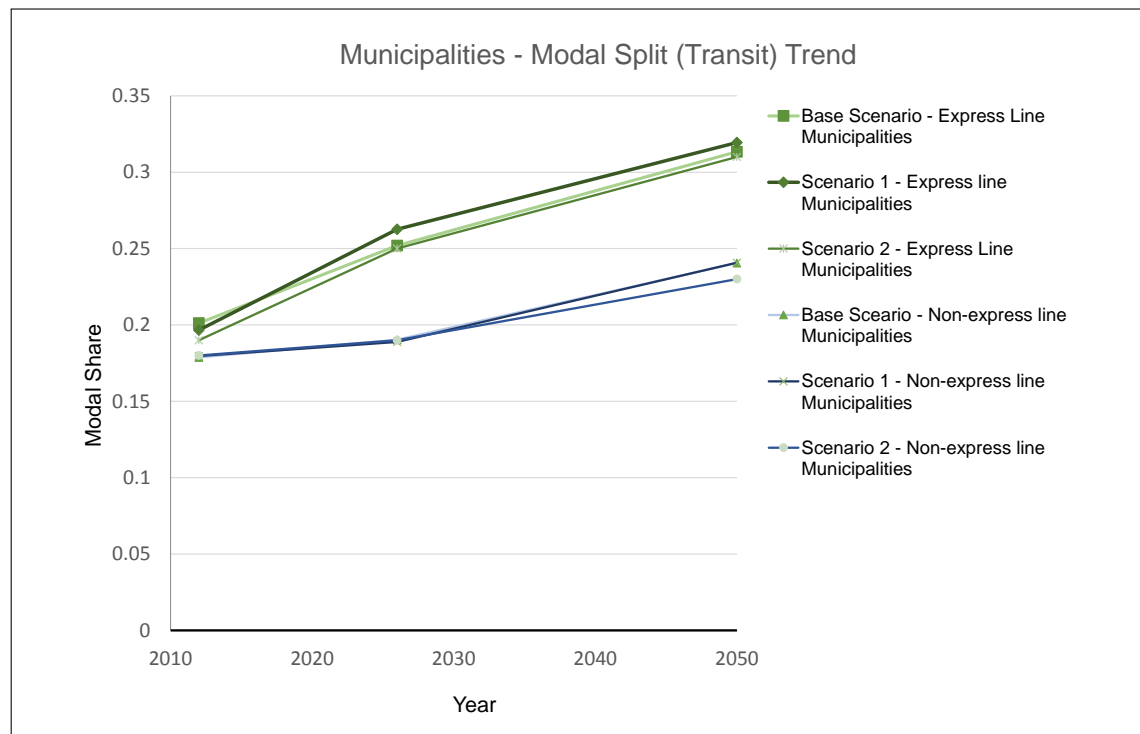


Figure 5.2: Modal Split at the Municipality Level

The municipality level analysis for modal split is important since a more realistic picture of the modal share is provided at this scale. Here, a distinction is made between the municipalities going to be served by the express lines of 2SS project and the municipalities not going to be affected by the express lines. It is evident from Figure 5.2 that the modal share in case of Express Line Municipalities for all three scenarios shifts upwards compared to Non-express line Municipalities. At year 2026, the transit share for Scenario 1 is the highest which is justifiable since the second Stammstrecke becomes operational in that year and the commute patterns shift slightly in favor of transit. The transit share for other two scenarios also rises in year 2026. In the year 2050, overall modal share for all the cases and scenarios increases compared to 2026. Again, the difference between Express line Municipalities and Non-Express Line Municipalities is significant. However, analyzing the Express line Municipalities only, the trend is mostly the same, like that in the case of 2026, with the modal split highest for the Scenario 1. However, gap is further narrowed down between the Scenario 1 and the other two scenarios, showing that the effect of the second Stammstrecke is going to peter out in the long run and there would be no real difference in modal share between the Base Scenario and the 2SS scenarios.

Zonal Level - Express Lines

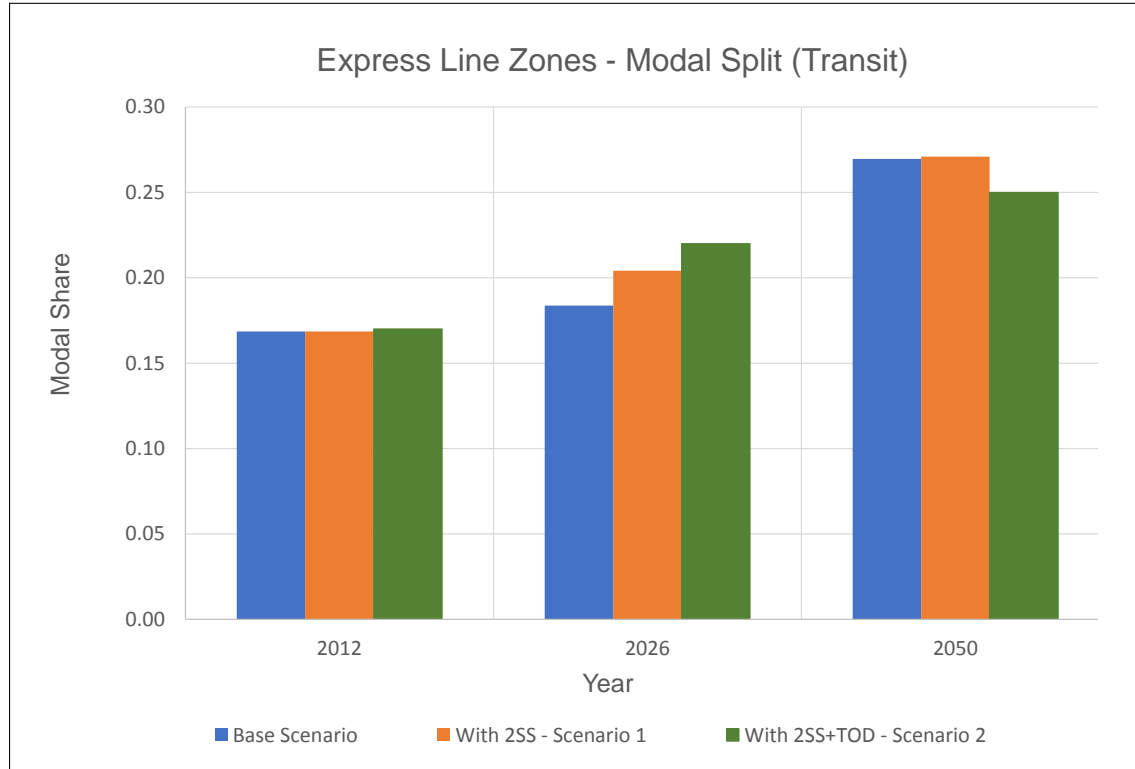


Figure 5.3: Modal Split at the Zonal level - Zones with Express Line Stops

The modal split situation at the smallest scale of analysis - zonal level - is shown in Figure 5.3. Expectedly, the modal split rises for all the scenarios in 2026 compared to year 2012. Delving further into the situation at 2026, the transit share is highest for Scenario 2, indicating that public transportation becomes slightly more attractive with TOD, compared to the situation when the second Stammstrecke becomes operational but there is no additional housing around the express line stops (Scenario 1).

The picture, however, changes in the year 2050 with the modal split for Scenario 2 being lower compared to the other two scenarios. One notable deduction from the bar chart at year 2050 is that the Base Scenario and Scenario 1 have the same value of modal share, strengthening the results from MMA and Municipality level analysis (Figure 5.1 and Figure 5.2). The effect of 2SS is supposed to diminish in the longer run and it would make no real difference to the transit share of the MMA, once the whole transit system settles down after the initial fluctuation in the inaugural year.

One caveat for the zonal analysis is that the number of trips originating in the zones is very low because only 5 percent of the total agents has been simulated in MATSim (explained in the previous chapter) and hence the numbers shown in Figure 5.3 are not the true representative of the actual situation.

5.2 Population

The second Stammstrecke is going to affect the population in one way or another. The overall population of the MMA is going to increase but it is pertinent to analyze how the population change is associated with the second Stammstrecke project.

MMA Level

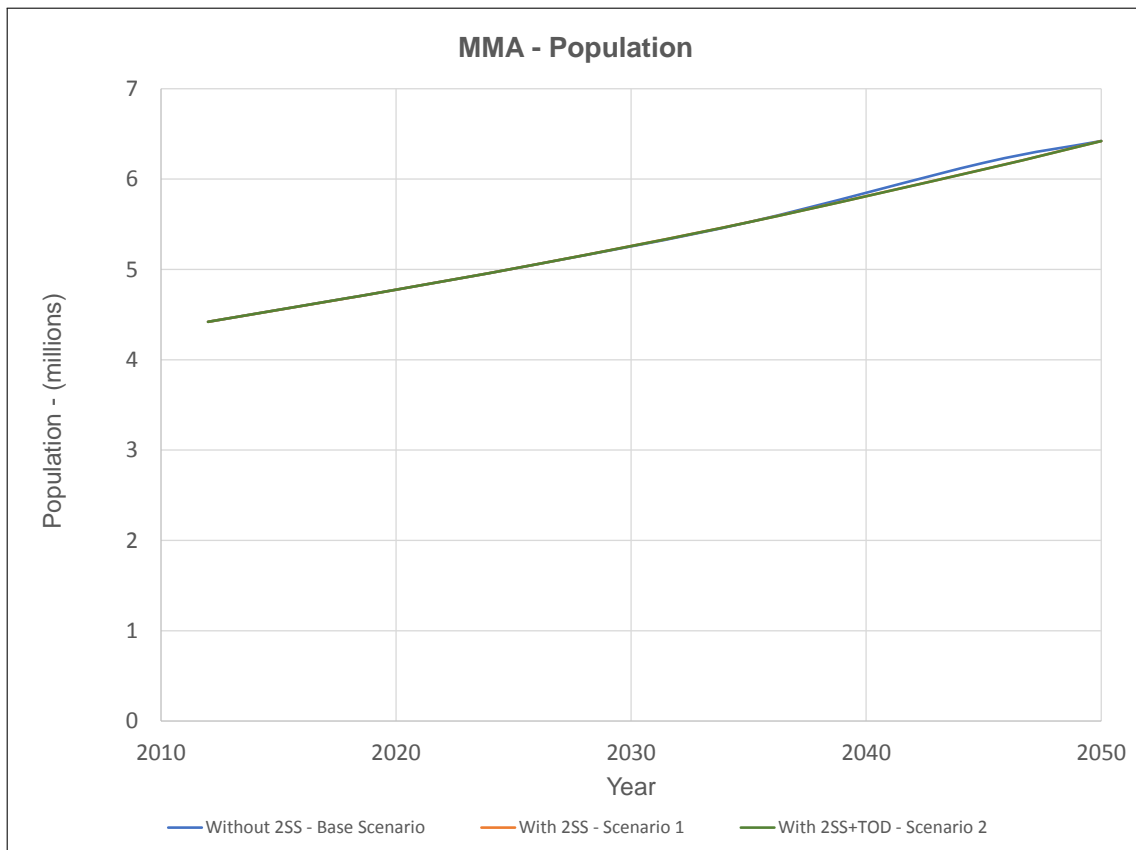


Figure 5.4: Population Trend - MMA

As evident from Figure 5.4, there is no real difference in the population levels at the MMA level between all three scenarios. The population is growing steadily over the course of the study period and all the three population lines are mirroring each other. There is slight increase in the population after the year 2040 till about 2047 in the Base Scenario which could be explained by the random nature of the model result and can be considered as an outlier in the grand scheme of things.

Municipality Level - Express Lines

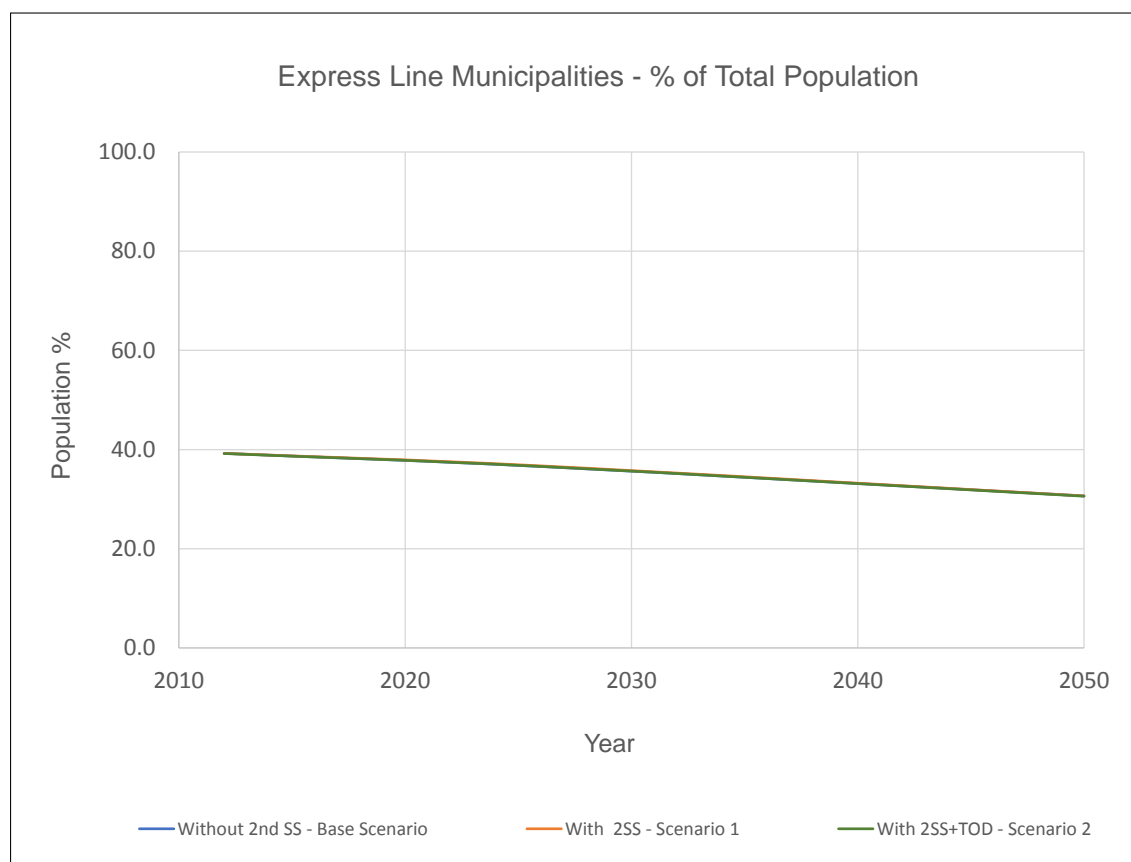


Figure 5.5: Percentage of Total Population - Express Lines Municipalities

Figure 5.5 shows the percentage of population in Express line districts over the course of study period. On first look, the population percentage is falling steadily for all three scenarios in the municipalities of concern. The trend demonstrates that the second Stammstrecke - Scenario 1 - and the associated TOD - Scenario 2 - are going to have no real impact on the population levels even in those municipalities which are going to be served by the express lines.

Moreover, the falling population numbers in the Express line Municipalities suggest that the attractiveness of these districts is going to go down in coming years and even the enhanced capacity of the transit is not going to result in higher population numbers in these municipalities.

Zonal Level - Express Lines

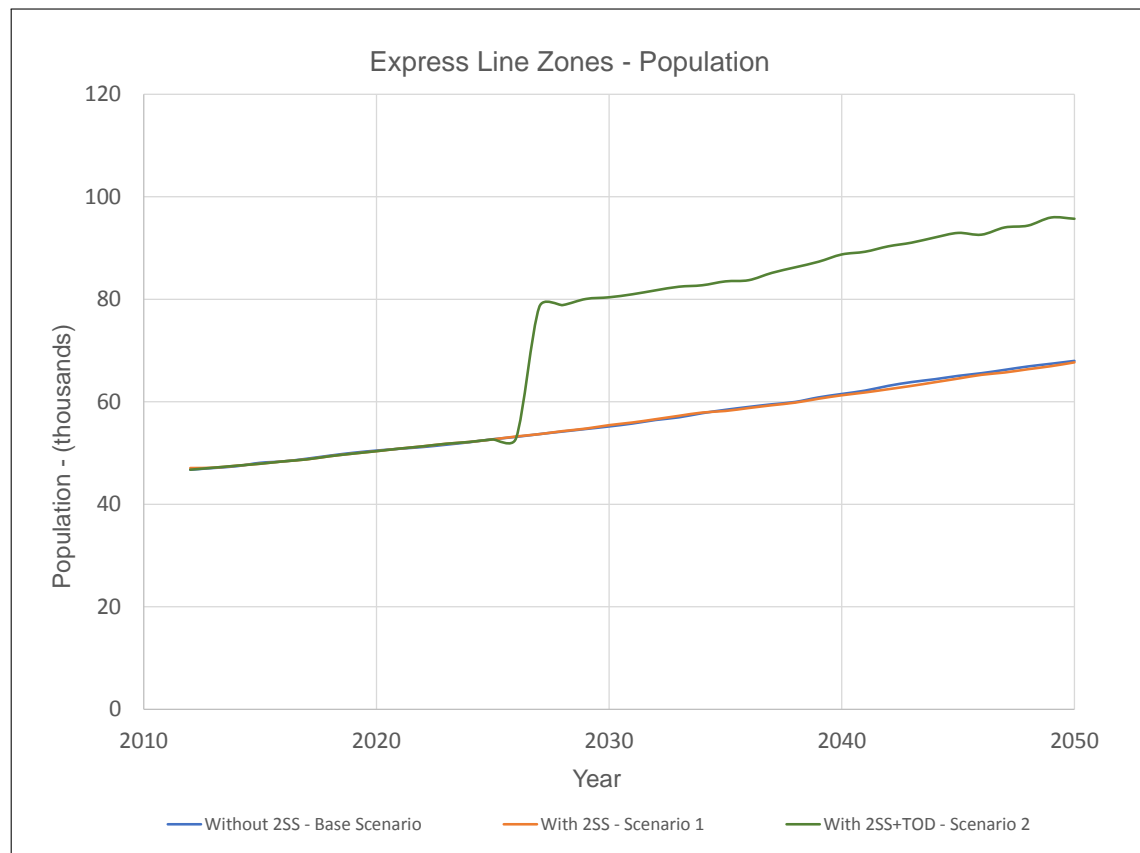


Figure 5.6: Population Trend - Express Lines Zones

The changes in population are presented at the zonal level for the Express line Zones in the Figure 5.6.

The population levels, as expected, mirror each other from 2012 till 2026. From 2026, there is a very sharp and sudden increase in the population for the Scenario 2 and this continues all the way till the conclusion of the study period. The trend for other two scenarios - Base and Scenario 1 - shows no real change and imitates each other till 2050.

The population results at the zonal level are in contrast with those at the MMA and the Municipality level, in particular for Scenario 2, which shows that at the smallest scale, the population levels do get influenced by the exogenous input of housing in the year 2026. The trend for all scenarios is also positive, unlike that in the case of Express Line Municipalities where the trend was going down.

The zonal analysis also shows that the attractiveness of the Express Line Zones becomes higher with the addition of housing in 2026 meaning people relocate to Express Line Zones with the provision of sufficient housing in those transit zones.

5.3 Jobs

Another land use parameter that is relevant to analyze is the employment. The employment parameter is going to be assessed at all three levels of analysis to check if there is any real impact on number of jobs at any level because of the second Stammstrecke.

MMA Level

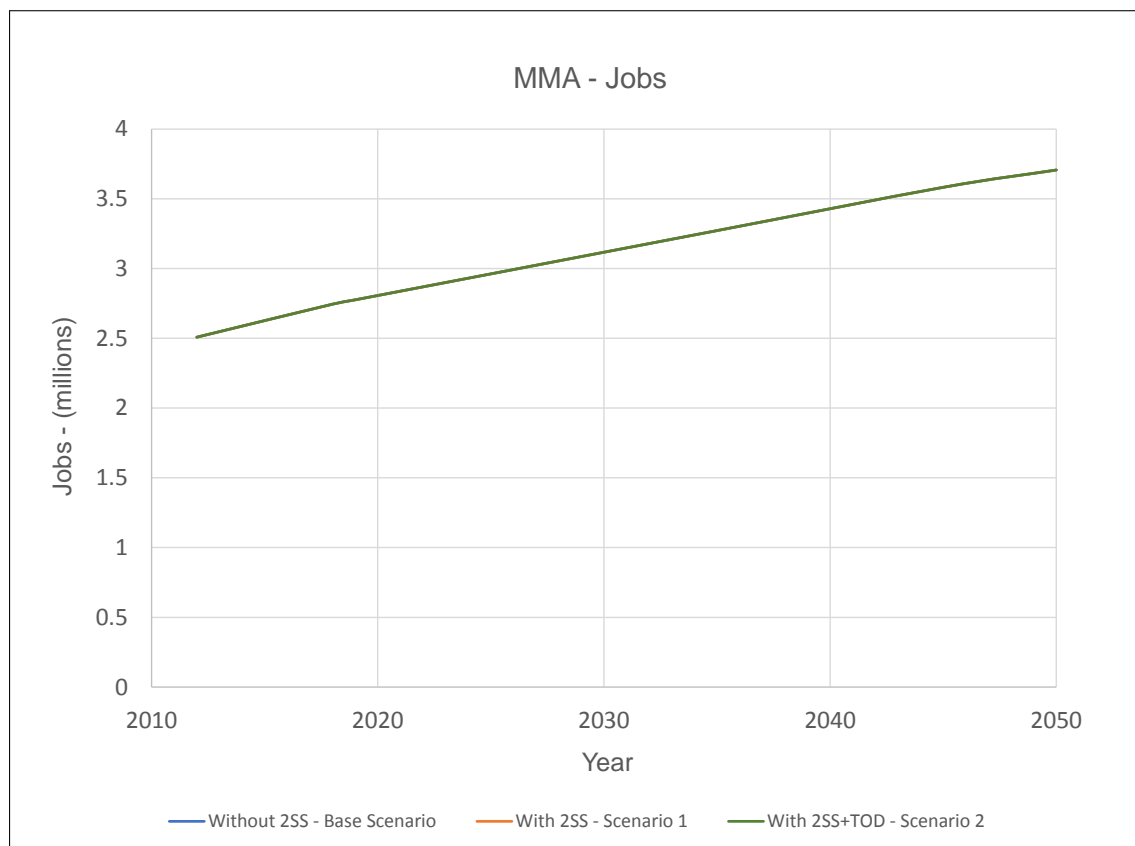


Figure 5.7: Jobs at MMA Level

Figure 5.7 shows the changes in job over the years for all the three scenarios at the MMA level.

It is evident from the graph that there is no effect of the two scenarios on number of jobs when compared to the Base Scenario. The number of jobs is increasing steadily in all the cases and corresponds to the increasing population trend shown in Figure 5.4. It is safe to deduce that the second Stammstrecke, in isolation as well as with TOD, is not going to have any effect on the number of jobs in the MMA.

Municipality Level - Express Lines

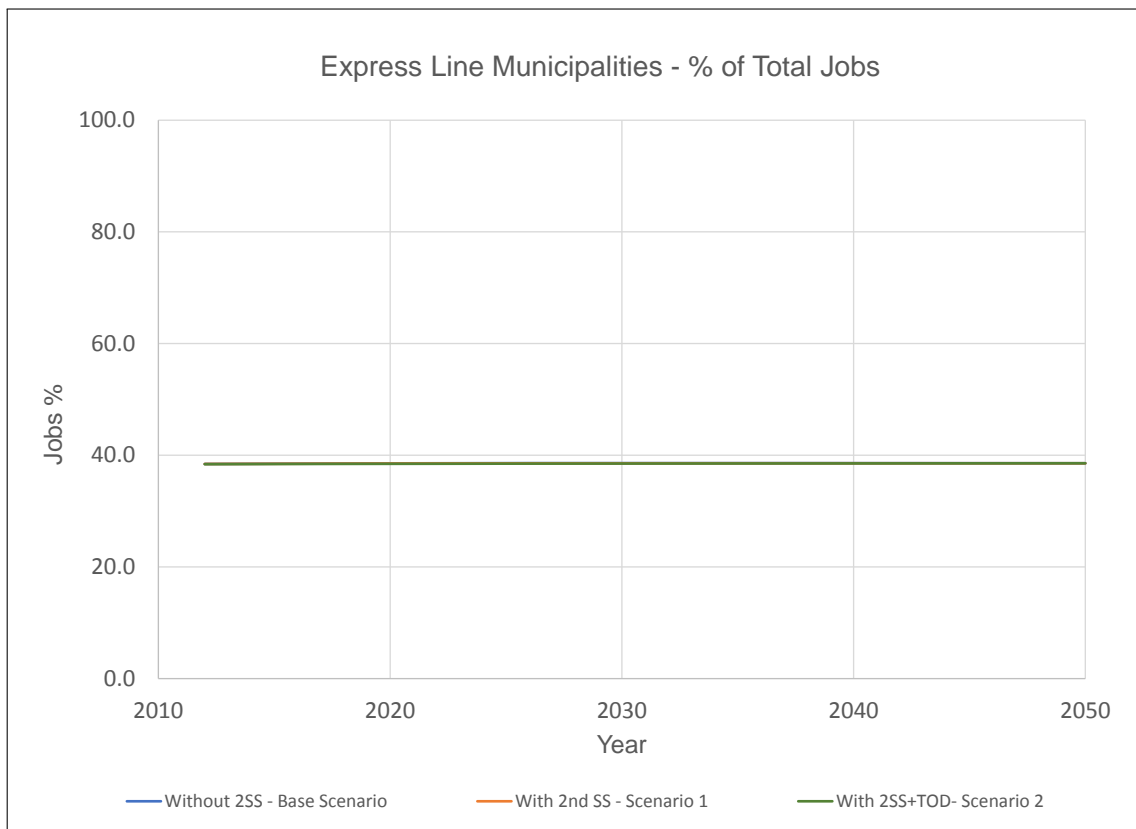


Figure 5.8: Percentage of Total number of Jobs - Express Line Municipalities

The results of the number of jobs at the Express Line Municipalities are presented in the Figure 5.8. The results are somewhat peculiar with the trend line being a flat one from the year 2012 till 2050 for all the three scenarios. This is possibly because of the fact that the number of jobs is interpolated for all years between base year and final year. Therefore, for each of three SILO runs, the number of jobs at each year is the same and hence the model is unable to detect any real change within the three scenarios.

Zonal Level - Express Lines

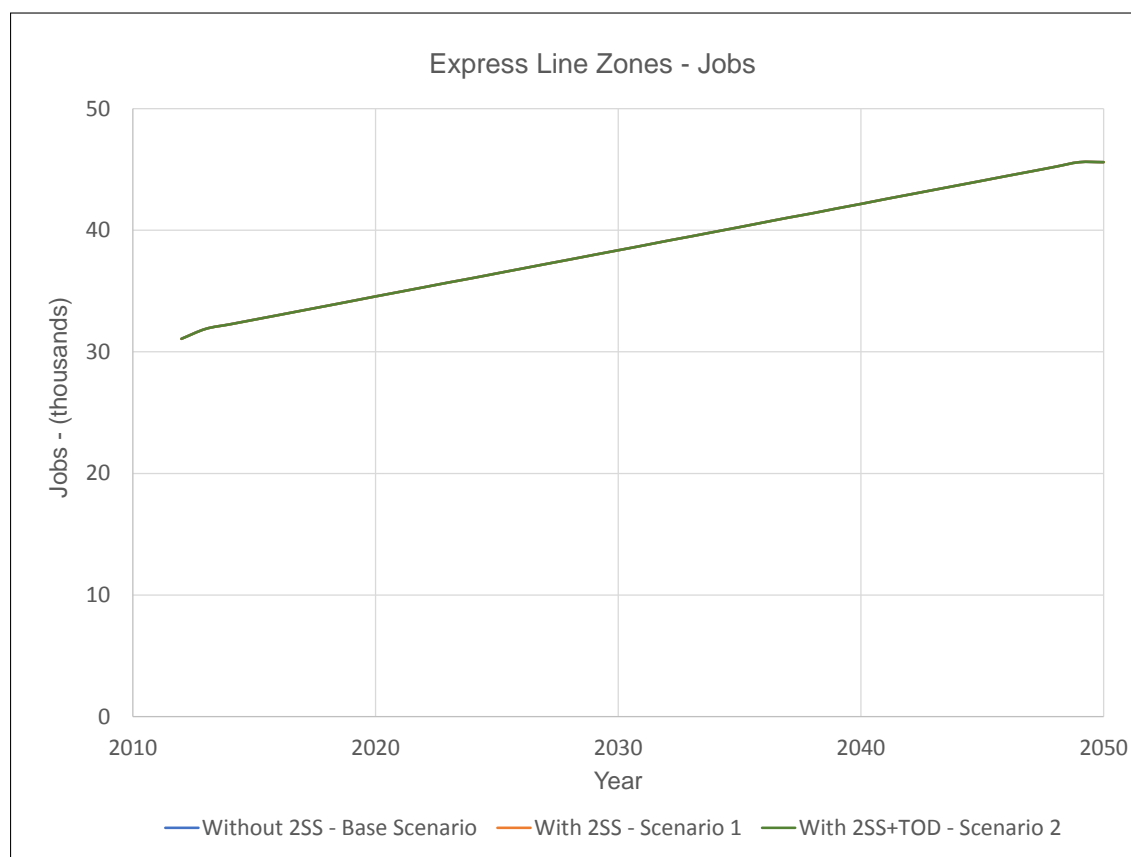


Figure 5.9: Total Number of Jobs - Express Line Zones

The number of jobs for all the Express Line Zones for all three scenarios is displayed in Figure 5.9. Again, owing to the limitation of the model, the job trend is identical for all the three scenarios. The flat region towards the end shows that the values for the two successive years, 2049 and 2050, are the same.

From all three graphs of the employment, it is hard to infer any trend and effect of the second Stammstrecke on the job situation of the region. Therefore, going by the results, which could have been obscured by model limitation in the employment module, it is cautiously concluded that the second Stammstrecke is going to have no impact on the employment.

5.4 Average Price

Another relevant parameter of land use to be evaluated for the second Stammstrecke impact is the average price of the housing in the Munich Metropolitan Area. The average price or rent would be examined at all three levels of analysis.

MMA Level



Figure 5.10: Average Rent in the MMA

The average price for all three scenarios at the MMA level is shown in Figure 5.10.

Overall trend evident from the graph points to a general decline in average rent across all the three scenarios for the study area. This indicates that the housing situation is going to improve in the coming years and the supply of dwelling units would be abundant which would lower the demand which in turn is going to lessen the monthly renting cost.

For the Base Scenario and Scenario 1, there is no gap or difference in average price over the course of the study period. However, in the Scenario 2, there is a notable drop from the year 2032 onwards till the conclusion of study period where the gap is the highest. This is a reasonable trend since dwelling units are added in the year 2026 and it takes a few years for the TOD effect to kick in on the overall average renting price of the MMA.

Municipality Level - Express Lines

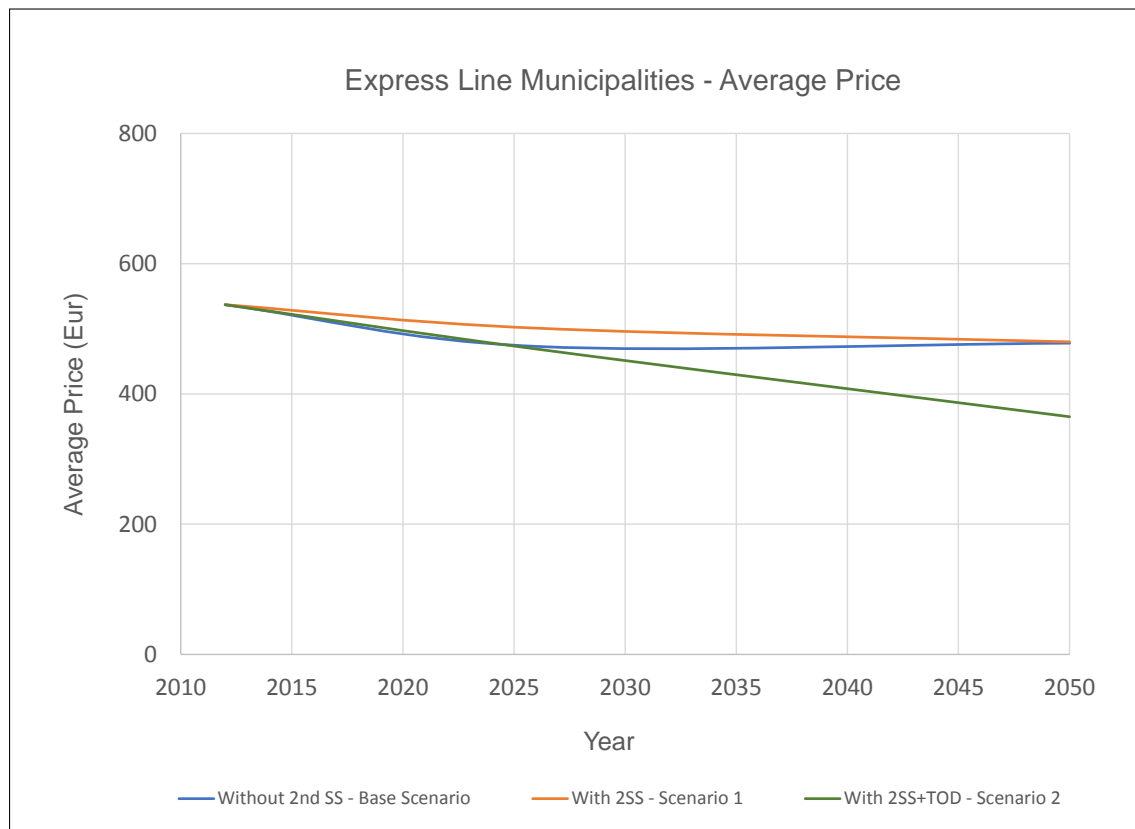


Figure 5.11: Average Rent - Express Line Municipalities

Figure 5.11 shows the average price of municipalities being served by the Express Lines.

Starting from year 2012, the three lines start at the same point but then gradually get separated from each other. The slight variation in the prices for the three scenarios in the initial years is due to the nature of the model which generated random output every time even if the model input stayed the same. Average price for the Base Scenario becomes almost stable from year 2026 onwards. For Scenario 1, the average price remains the highest till it overlaps the Base Scenario in the final five years. The reason for the higher average price in the case of Scenario 1 could be explained by the fact that the municipalities with the Express lines become attractive for living due to the express line going through them and the higher demand generated for housing causes the price to move upwards.

The average renting costs for Scenario 2 decline rapidly from the year 2026 onwards and keep going down steadily all the way till 2050. This is a reasonable trend considering the fact that every municipality where the express stops are located has been provided with 1000 additional housing. The excess of dwelling units results in a drop of price in these municipalities and the situation stays the same in the final year where the average price is the lowest, indicating that the dwelling units are still surplus and then corresponding demand is still very low.

Zonal Level - Express Lines



Figure 5.12: Average Rent - Express Lines Zones

The average renting cost in the Express Line Zones is presented in Figure 5.12. The impact of all three scenarios on the average price is reported in the graph. There is no difference in the average price from the starting year till year 2026 which is fully backed up by conceptual development timeline of the scenarios. From 2026 onwards, the average price for Base Scenario and Scenario 1 follows an identical path till the final year. This means that there is no impact of the express lines at the zonal level on average monthly renting costs.

The situation however changes substantially in Scenario 2 at year 2026, where a rapid fall in average price is seen which is totally rational since the Express Line Zones get excessive housing which results in massive price drop. The prices slightly go up at year 2027 which probably means that a slight increase in demand is experienced. From 2027 onwards, however, the prices continue to plummet steadily till 2050.

5.5 Accessibility

One of the basic land use parameters that is also associated directly with the transport is the accessibility. The model generates auto and transit accessibilities and it is appropriate to study the impacts on accessibility for all three scenarios.

MMA Level

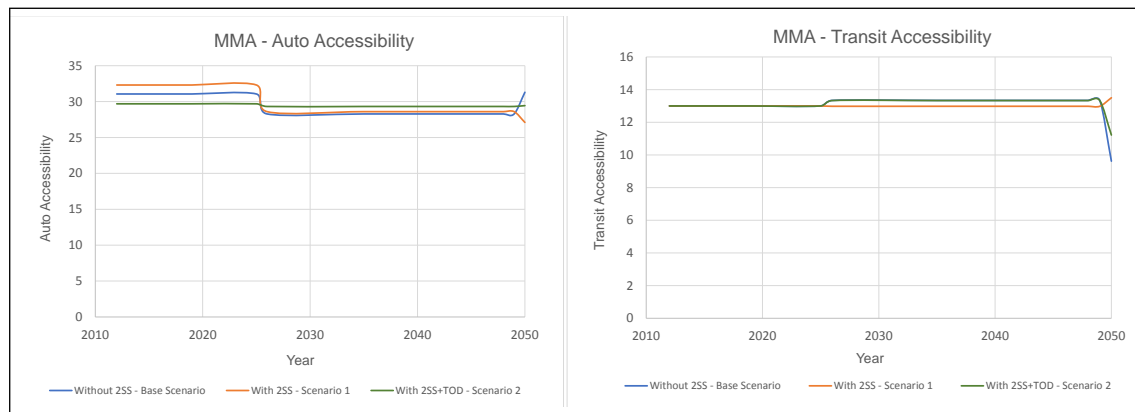


Figure 5.13: Accessibility at MMA Level - Auto and Transit

The accessibility indices for auto and transit at the MMA level are given by Figure 5.13 for all three scenarios. Again owing to the model characteristic, the auto accessibility of the three scenarios is different at the starting year even when the transport data being fed into the model is the same for all three cases till 2026. The transit accessibility, however, stays the same which represents the actual situation.

For all the scenarios, the auto accessibility falls down in the year 2026 which indicates that the travel time by car has gone up in the year the second Stammstrecke opens and the congestion has increased. On the other hand, the transit accessibility in the same year goes up, corresponding to the positive effect of second Stammstrecke.

In the final transport model run - in the year 2050 - the auto accessibility rises in the Base Scenario while it goes down further for the Scenario 1. The situation is contrary in the transit accessibility side where transit accessibility falls in Base as well Scenario 2 but increases slightly in Scenario 1. This indicates that without making any changes to the entire network - private and public - the travel time by car to various destination has gone down than the previous years and hence results in better auto accessibility. But for the same scenario, the travel time by transit has increased and resultantly the transit accessibility deteriorates. On the other hand, with a revamped S-bahn system with express lines in place, the transit accessibility finally increases somewhat compared to the year it opens i-e 2026 but more congestion on private network has resulted in lower attractiveness for cars and hence a lower auto accessibility value.

Zonal Level - Express Lines

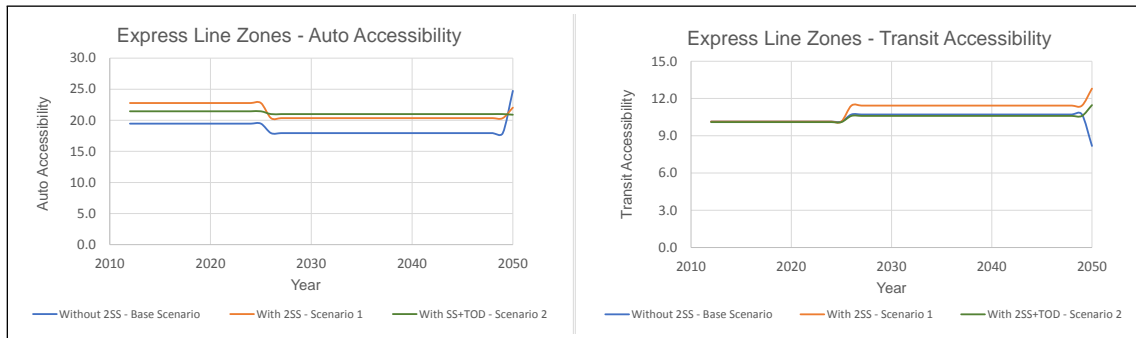


Figure 5.14: Accessibility in Express Line Zones - Auto and Transit

Figure 5.14 shows the accessibility values in the Express Line Zones for all the scenarios.

The trend is fairly similar to the one seen at the MMA level. For all three scenarios, the auto accessibility in the year 2026 goes down while the transit accessibility rises. For Scenario 1, the rise in transit accessibility is the highest which puts into perspective the initial effect of the whole second Stammstrecke in the Express line Zones. In the year 2050, the auto and transit accessibilities further improve for Scenario 1, highlighting the overall positive effect on the travel times of second Stammstrecke. For the Base Scenario, the auto accessibility rises again in 2050, mirroring the situation at the MMA level, while it falls significantly on the transit side, indicating that the transit network with no changes is forecasted to enhance the travel times by transit in the Express line Zones.

5.6 Car Ownership

One parameter that gets directly affected by the land use and transport interaction is the auto ownership level. Therefore, it is also appropriate to check the effects of second Stammstrecke on car ownership in the study area.

MMA Level

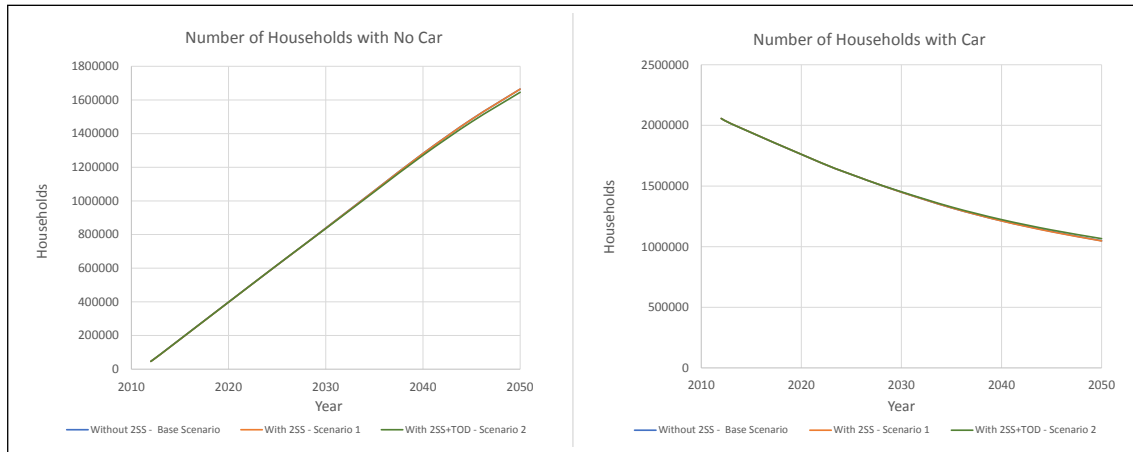


Figure 5.15: Car Ownership Situation at the MMA Level

Number of households with no car is compared with the number of households with car(s) in the Figure 5.15. Generally, for all the scenarios, car ownership levels are projected to go down over the course of the study period. There is no visible difference between the three scenarios, especially in the first half of the study period. From 2035 onwards, households with no car are rising at a slightly greater rate in Scenario 1 than the other two scenarios. In the final year of the study period, gap between the households with no car in Scenario 1 versus other two scenarios is the widest. This is slightly unexpected, mainly because one would expect that with TOD scenario (Scenario 2), more households would be giving up their cars because of superior transit connections but the model predicts otherwise and infers that the TOD in the Express line Zones is not going to propagate the effects at the MMA level. Nevertheless, it is still plausible that the revamped S-bahn network with second Stammstrecke results in lesser car ownership - albeit very minute - when compared with the Base Scenario.

Chapter 6

Conclusion

The thesis strived to assess and analyze the impacts of second central S-bahn line, the second Stammstrecke, on the land use parameters as well as the transport characteristics. In order to achieve this, a state of the art ILUT model, SILO-MATSim, was used. The study area for the impact assessment in this thesis was Munich Metropolitan Area which, in turn, is the region where this model has been implemented. Three scenarios were developed in order to compare the results and to properly analyze the effects of second Stammstrecke against some benchmark. First scenario was the traditional, Base Scenario, which basis around no changes to the existing situation of transportation network and assumes that no addition or improvement of the network takes place. The second scenario is the application of second Stammstrecke in the year 2026 and the subsequent changes to the public transport network. Scenario 3 was a hypothetical scenario which revolved around exogenous housing addition around the Express Line Stops of the second Stammstrecke, referred as 2SS plus TOD scenario in this thesis.

The study period under consideration was from year 2011 to 2050, with the analysis carried out between years 2012 (the year the transport model runs for the first time) and 2050, with particular focus on the year 2026 and 2050. The transport data was modified to include the changes to lines, stations and schedule because of second Stammstrecke. For the existing lines that will be the part of revamped S-bahn network under second Stammstrecke, the schedule was determined using the travel time information from MVV. For the new lines, where no information was available regarding travel time and schedule, travel time computations and subsequent schedule-making was done using suitable assumptions. The zone to zone travel times produced by skim matrices were checked to establish the veracity of the travel data. Three simulations were then run to yield the output data for the three scenarios. The transport model was run thrice - in the year 2012, 2026 and 2050 - for each scenario. In order to reduce the simulation period, a scaling factor of 5 percent was chosen which meant that 5 percent of the total agents were simulated in the transport model runs. For the Scenario 2, 1000 housing units were added in each of the zones where Express Line Stops were located in the year 2026 - the year when the second Stammstrecke opens.

Scenario analysis was then performed at three different resolution levels - MMA, Express Line Municipalities and Express Line Zones. The transit share increases slightly for Scenario 1, in comparison with other two scenarios, in the year 2026 but became equal to other two scenarios in the year 2050. When analyzed at the municipality level, the municipalities with Express Line stops had the highest transit share in the year 2026 and 2050. The modal share in the municipalities without Express Line stops was considerably lower throughout the study period for all three scenarios, indicating that the second Stammstrecke did result in an increased transit share but the difference was not too glaring. The population is scheduled to increase for all the scenarios at all three resolution levels. While analyzing the population at the zonal level, it was observed that for the Scenario 2, the population increase took place at a considerably higher rate than rest of the scenarios, showing that TOD resulted in a significant population growth in the Express line Zones. The employment levels for all three scenarios at all resolution levels increased at the same rate, indicating no effect of second Stammstrecke on the number of jobs.

Average price of housing declined over the course of study period for all three scenarios with the decline for Scenario 2 being the highest, indicating that there was over supply of housing in the Express Line Zones. The auto accessibility declined while transit accessibility increased in 2026 for all the scenarios. The year 2050 saw an increase in the auto accessibility for the Base Scenario while it went down further for Scenario 1. The transit accessibility only rose in case of Scenario 1 in the same year while it went down for other two scenarios. The results at the zonal level were more or less the same, with the difference observed in year 2050 where auto accessibility slightly improves in Scenario 1 as well. The transit accessibility improves for Scenario 2 in the Express Line Zones in the year 2050 unlike at the MMA level where it had deteriorated in the same year. The auto ownership levels dwindle for all three scenarios over the years, with the decline being highest in the case of Scenario 1.

Overall, considering all the analyzed parameters, it would be safe to conclude that the impact of second Stammstrecke on the land use and transport side is not massive. Parameters like modal split, accessibility and car ownership do show a constructive effect of the 2nd Stammstrecke but it is not substantial even when analyzed at the zonal level where it is supposed to show the biggest impact out of the three levels of analysis. Other evaluated parameters show little to no difference with the Base Scenario, indicating that the impact of second Stammstrecke is, by and large, fairly minimal.

Another important conclusion drawn from this thesis underscores the importance of developing housing infrastructure along with any major transit development. Scenario 2 (The 2nd Stammstrecke plus TOD Scenario) not only displayed the positive impacts of Scenario 1 (The 2nd Stammstrecke Scenario) on modal split and accessibility - albeit in lesser magnitude - but also demonstrated productive effects on population (Express Line Zones) and average price.

6.1 Limitations and Future Work

- Due to lack of availability of transit data for the second Stammstrecke, a lot of assumptions and suppositions were carried out which might have resulted in generous travel times, used in the trip calculation. Therefore, it is difficult to establish how valid the predictive results of all three scenarios are.
- After model implementation for the three scenarios, it was found out that some of the S-bahn lines were scheduled to run with a headway of 15 minutes but for the transit input data for MATSim, it was assumed that all the S-bahn lines would run with a headway of 20 minutes.
- The S-bahn system under second Stammstrecke is scheduled to be constantly revised till it begins operation in 2026. Therefore, the network and schedule changes done in this thesis might not turn out to be the final version of the changes under the revamped S-bahn system. The network changes adapted were based on the April 2017 version of the revamped system.
- The scaling factor of 5 percent turned out to be too low to yield reliable results. When analyzed at the zonal levels, the number of trips in smaller zones was too small, to the point that some of the zones had no trips. That was the reason for the inclusion of the bigger municipality level in the analysis.
- Due to operational limitation of the model, it had to be run from 2011 to 2050 for all three scenarios when the two of the scenarios only kick in from 2026 onwards. Owing to the random-execution nature of the model, the results produced for two simulation will always be different even with the same input data. The different values of various parameters, in scenario analysis, seen from the year 2011 to year 2026 are explained by this model characteristic.
- The accessibility values stay the same till the next transport model run year. Since the transport model was only run in years 2012, 2026 and 2050, therefore the model for the large part stayed insensitive to the accessibility values and was unable to display the progressive impact of second Stammstrecke on accessibility.
- After the analysis, the number of housing units added in each of the Express Line Zones for the Scenario 2 seemed too high. The parameters like population and average price show massive incline and decline respectively, confirming the generous selection of the number.
- The employment parameter showed very insensitive results indicating that model probably needs more refining in the job estimation module.

Future work should include the consistent updating of the transit data under the second Stammstrecke and addressing all the limitations that are reported above to improve the reliability of the results.

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Appendix A

Trip Building for an S-bahn Line

Table A.1: Schedule of one train for the Express Line S23x

Line	From Stop	To Stop	Departure Time(s)	Arrival Time(s)	Travel Time(s)
S23x	Mering	Althegnenberg	28800	28980	180
S23x	Althegnenberg	Haspelmoor	29000	29060	60
S23x	Haspelmoor	Mammendorf	29080	29200	120
S23x	Mammendorf	Malching	29220	29340	120
S23x	Malching	Maisach	29360	29480	120
S23x	Maisach	Olching	29500	29715	215
S23x	Olching	Gröbenzell	29735	29855	120
S23x	Gröbenzell	Pasing	29875	30285	410
S23x	Pasing	Laim	30305	30425	120
S23x	Laim	HBF	30445	30611	166
S23x	HBF	Marienhof	30631	30698	67
S23x	Marienhof	München Ost	30718	30831	113
S23x	München Ost	Flughafen Besucherpark	30851	31911	1060
S23x	Flughafen Besucherpark	Flughafen München	31931	32051	120
S23x	Flughafen München	Flughafen Besucherpark	28800	28920	120

Line	From Stop	To Stop	Departure Time(s)	Arrival Time(s)	Travel Time(s)
S23x	Flughafen Besucherpark	München Ost	28940	30000	1060
S23x	München Ost	Marienthof	30020	30133	113
S23x	Marienthof	HBF	30153	30220	67
S23x	HBF	Laim	30240	30406	166
S23x	Laim	Pasing	30426	30546	120
S23x	Pasing	Gröbenzell	30566	30976	410
S23x	Gröbenzell	Olching	30996	31116	120
S23x	Olching	Maisach	31136	31351	215
S23x	Maisach	Malching	31371	31491	120
S23x	Malching	Mammendorf	31511	31631	120
S23x	Mammendorf	Haspelmoor	31651	31771	120
S23x	Haspelmoor	Althegnenberg	31791	31851	60
S23x	Althegnenberg	Mering	31871	32051	180

Appendix B

In Transit travel time from an origin zone to selected destinations

Table B.1: In transit travel time from an origin zone (HBF) to selected destinations

Origin Zone (HBF)	Destination Zones	Zone name	Travel time before(min)	Travel time after(min)
3504	3781	Englschalking	17	11
3504	2291	Erding	19	24
3504	1617	Freising	16	16
3504	1158	Petershausen	19	12
3504	1061	Mering	28	30
3504	2424	Geltendorf	26	23
3504	3160	Herrsching	31	40
3504	4597	Holzkirchen	33	35
3504	4476	Aying	32	34
3504	4677	Grafring	19	18
3504	1659	Flughafen	33	26

Appendix C

Express Line Zones - Visualisation in Munich

Zones with Express Line Stops in Munich

Population

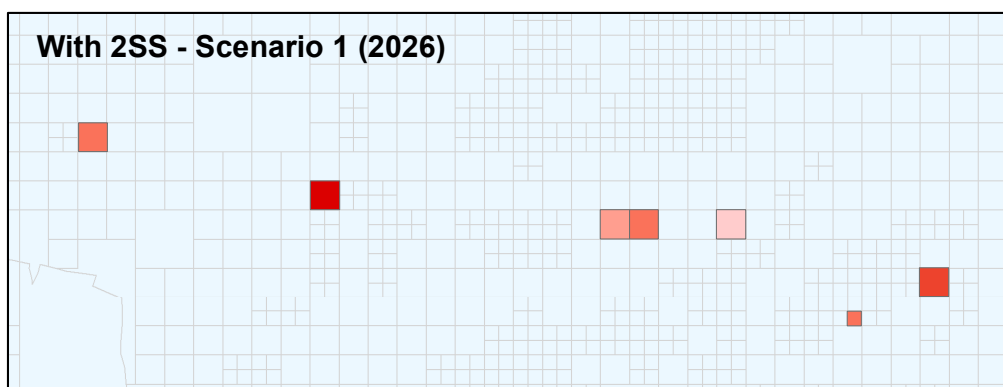
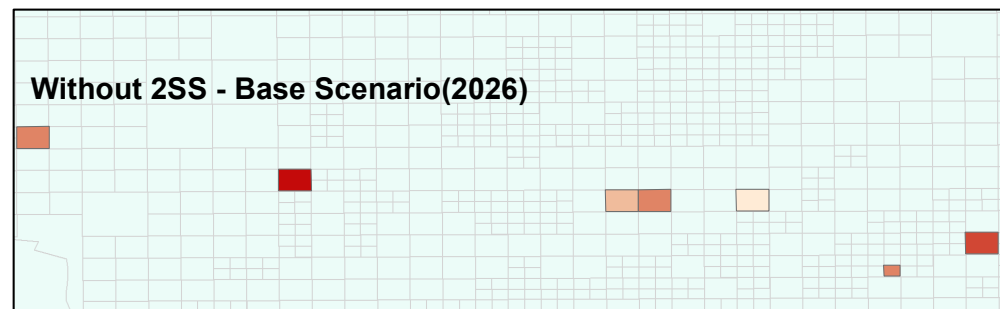
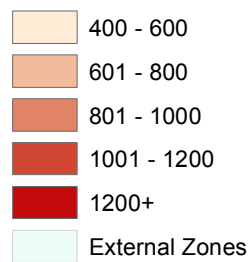


Figure C.1: Population Visualization in 2026

Zones with Express Line Stops in Munich

Average Price

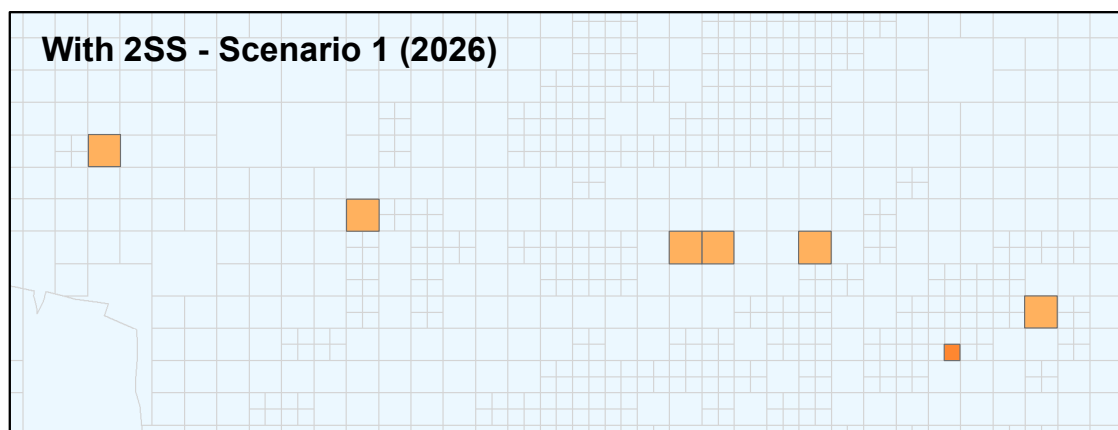
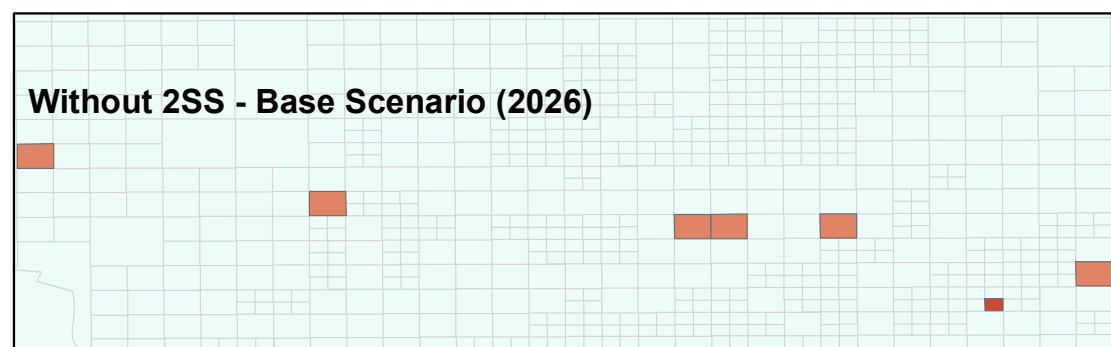
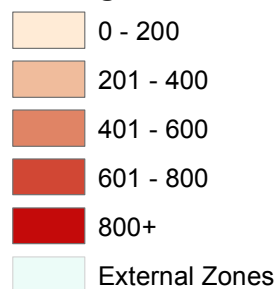


Figure C.2: Average Price Visualization in 2026

Zones with Express Line Stops in Munich

Transit Accessibility

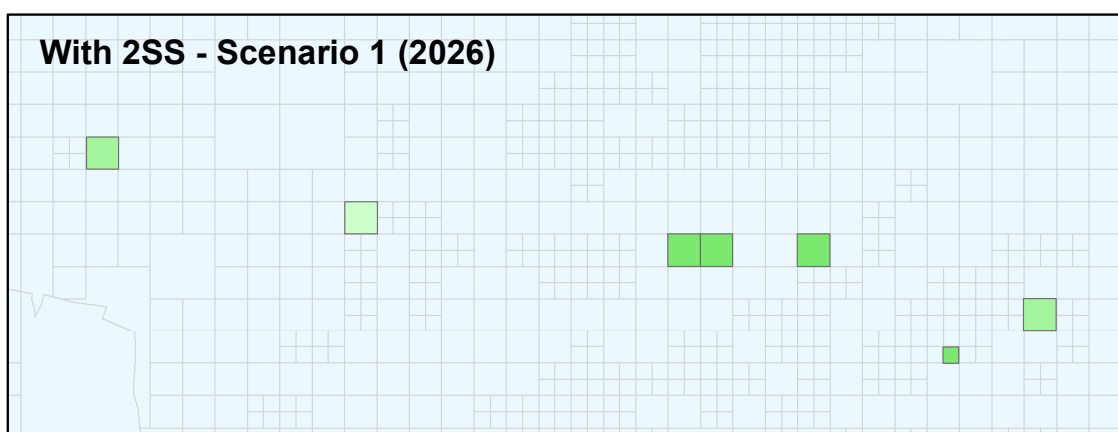
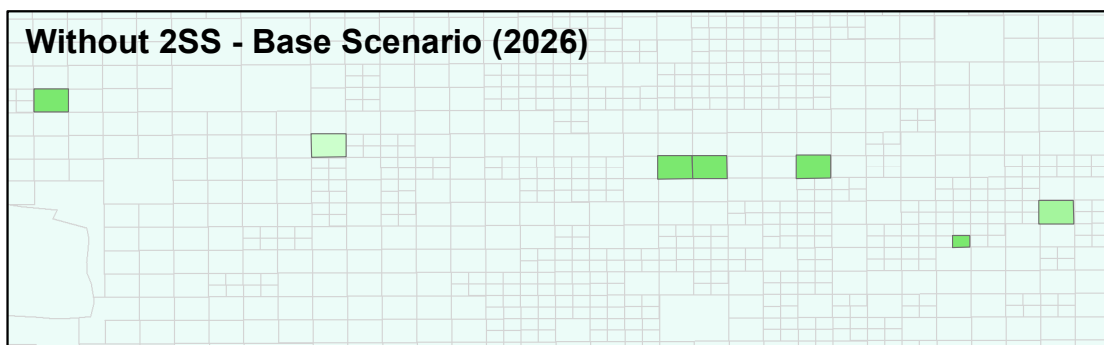
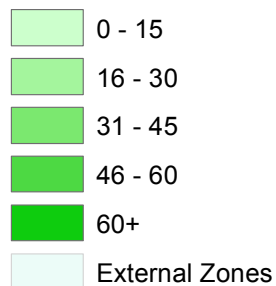


Figure C.3: Transit Accessibility Visualization in 2026

Zones with Express Line Stops in Munich

Population

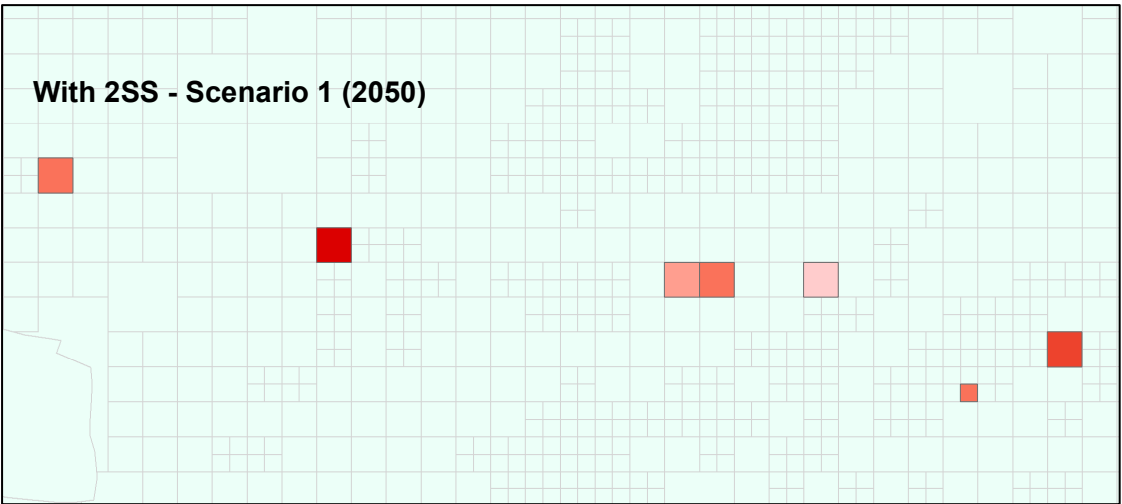
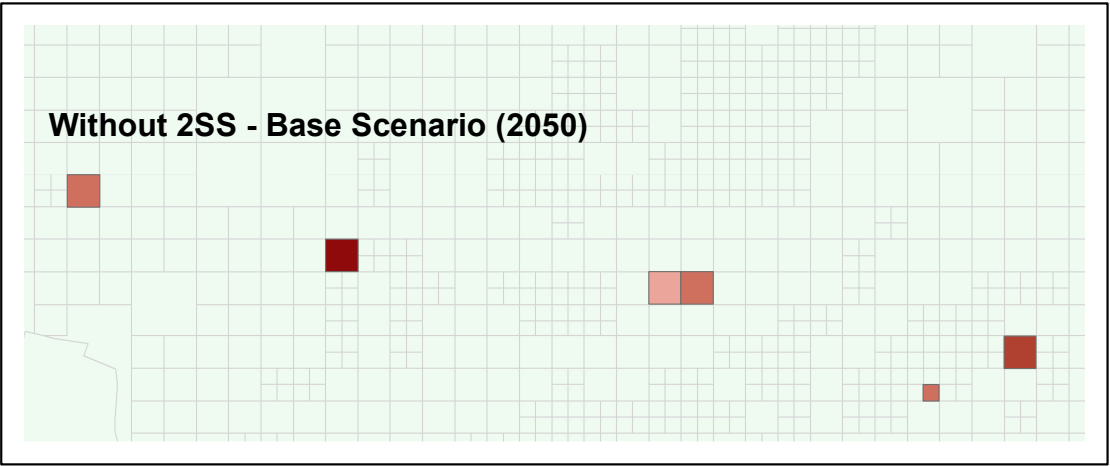
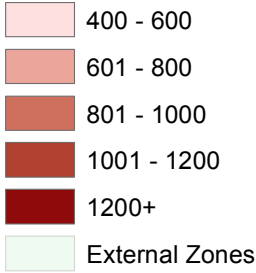


Figure C.4: Population Visualization in 2050

Zones with Express Line Stops in Munich

Average Price

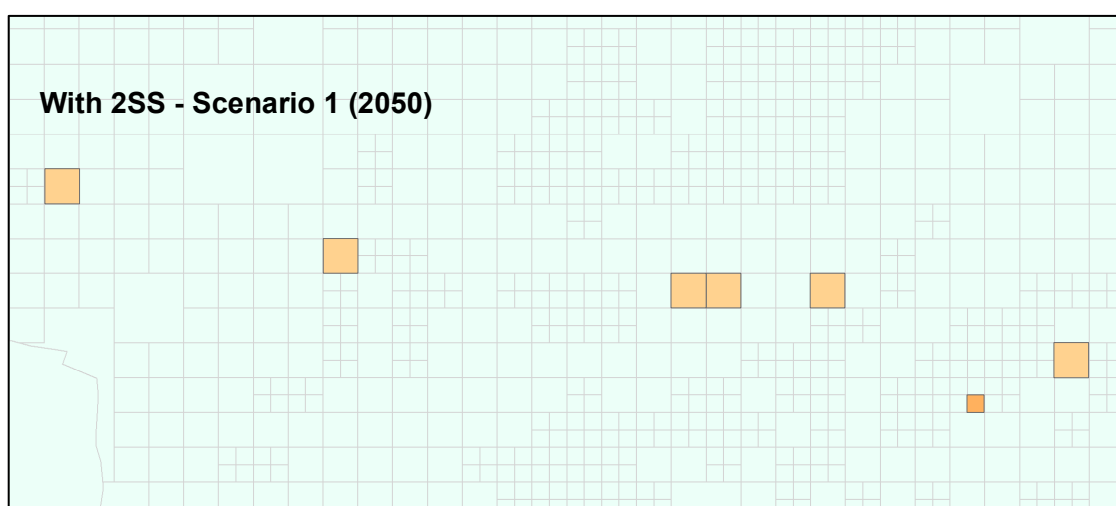
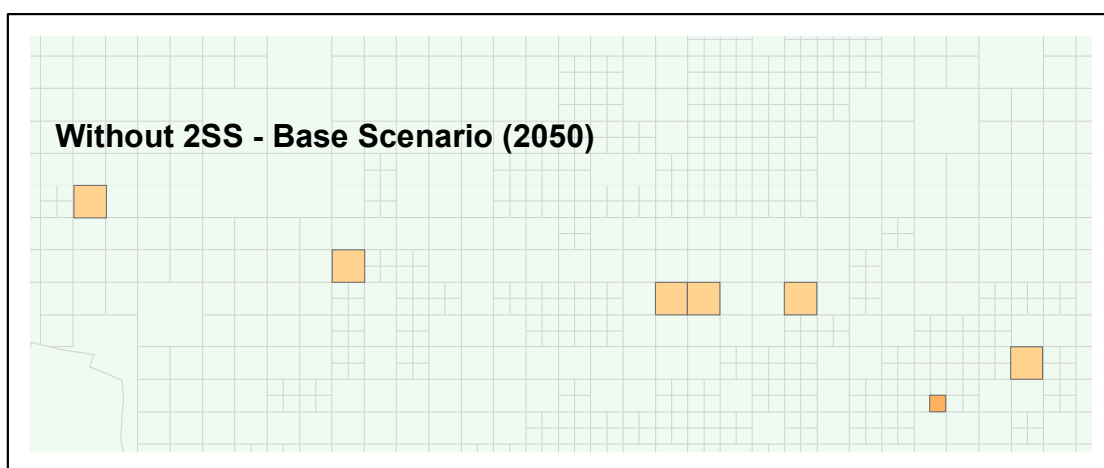
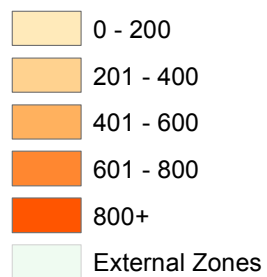


Figure C.5: Average Price Visualization in 2050

Zones with Express Line Stops in Munich
Transit Accessibility

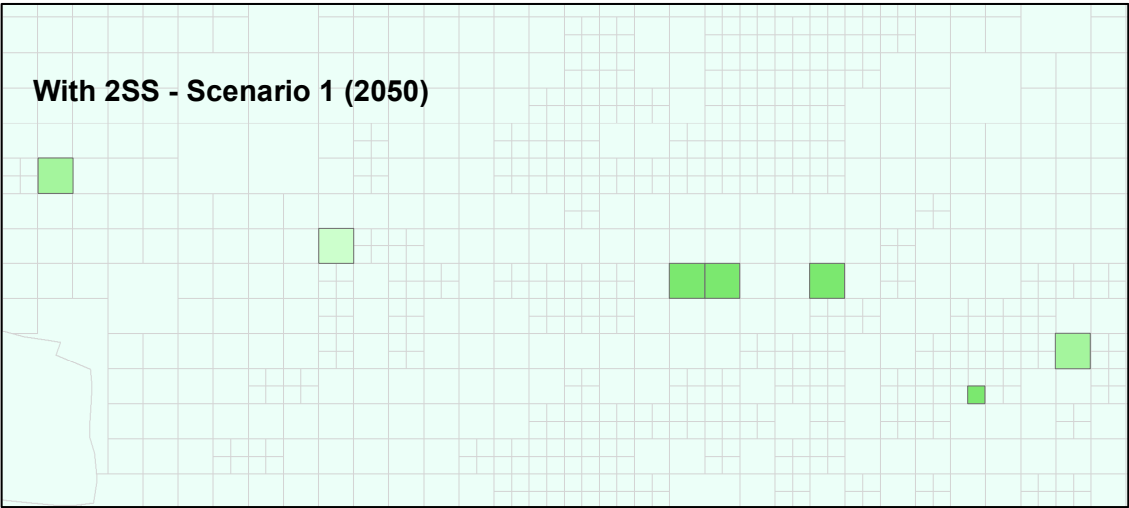
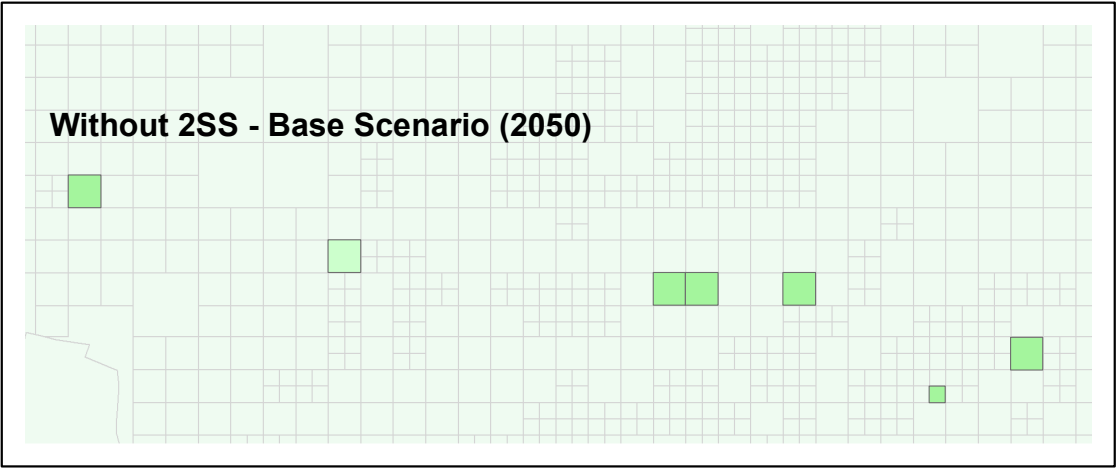
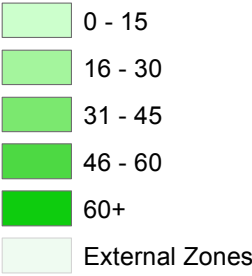


Figure C.6: Transit Accessibility Visualization in 2050

Appendix D

Express Line Municipalities - Modal Split (Transit)

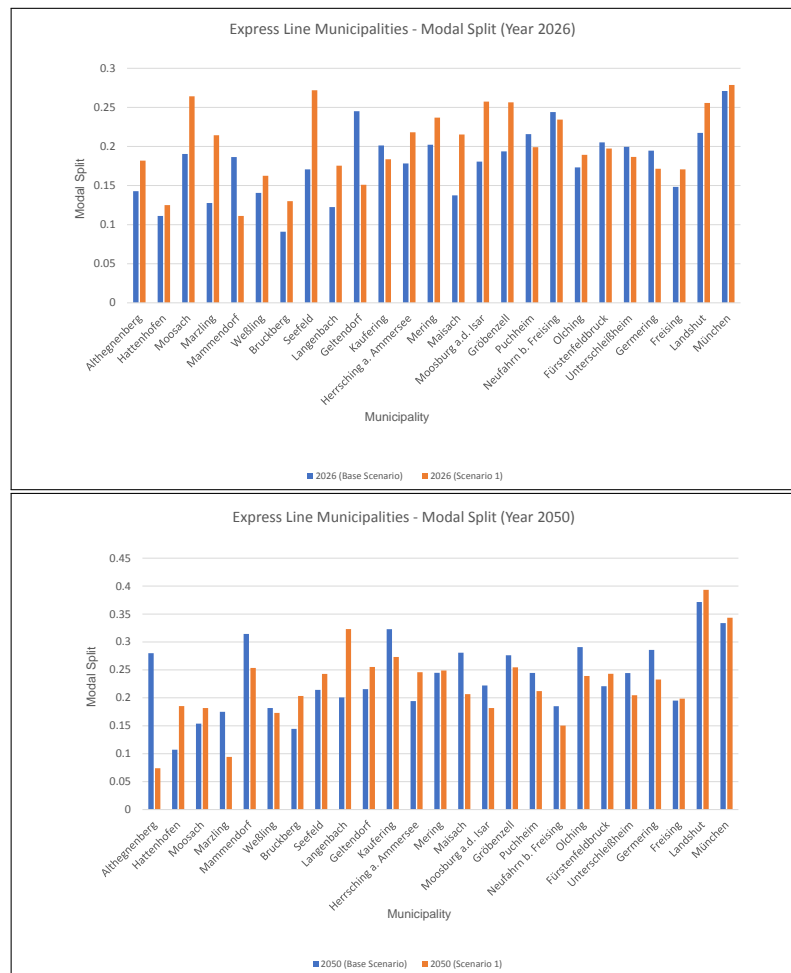


Figure D.1: Modal Split in Municipalities

Erklärung

Ich versichere hiermit, dass ich die vorliegende Arbeit selbstständig verfasst und keine anderen als die im Literaturverzeichnis angegebenen Quellen benutzt habe. Alle Stellen, die wörtlich oder sinngemäß aus veröffentlichten oder noch nicht veröffentlichten Quellen entnommen sind, sind als solche kenntlich gemacht. Die Zeichnungen oder Abbildungen in dieser Arbeit sind von mir selbst erstellt worden oder mit einem entsprechenden Quellennachweis versehen. Diese Arbeit ist in gleicher oder ähnlicher Form noch bei keiner anderen Prüfungsbehörde eingereicht worden.

München, 06 February 2018

Saveez Sheikh