Urban spatial structure in relation to intermodal competition in long-distance travel

The case of Berlin and München

Version	Final
Date	28 June 2018
Author	Tibor Rongen
Student number	S1014704
Supervisor	Prof. dr. P.M. Ache

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Preface

In front of you is my bachelor's thesis in the field of Geography, Planning and Environment. This paper is the final piece of the pre-master programme in Spatial Planning which I started last September. The last months I have worked with lots of devotion on this research. The subject of intermodal competition has fascinated me for some time now, so I was happy to investigate this research area on a daily basis.

From time to time I was however too fixated at certain direction to continue my research in since I spent a lot of time orientating on new approaches. In the final stage this unfortunately resulted in a time shortage. This has however been a good lesson for me to better consider the structure of my research on forehand. Fortunately, the advice of Mr. Ache helped me to get back on track and to structure my research process. Herewith, I would like to thank him for the support during the course of writing this thesis. Finally, I would like to thank my friends and family for their motivation and support.

I hope you will enjoy reading this paper.

Utrecht, June 2018

Tibor Rongen

Abstract

The recent completion of the Verkehrsprojekt Deutsche Einheit nr. 8 has enabled the High-Speed Train (HST) to travel between Berlin and München in under four hours. This development has revived the public debate on the possible substitutive role of the HST in relation to the aircraft on this route. This paper analyses the extent to which urban spatial structure influences the intermodal competition between HST and the aircraft in the Berlin-München market. Considering the central three parameters of transport mode service level, urban spatial structure and terminal accessibility this research attempted to tackle this research problem. The results show that urban spatial structure on the level of the functional urban areas (FUA) are to a limited extent in favour of the HST. However, comparing two different transport markets requires more refinement in which this paper provides a spatial perspective.

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1. Introduction

Recently, the construction of a direct High-Speed Train (HST) connection was completed between the urban areas of Berlin and München. The distance between the two German cities is approximately 600 kilometres and due to this new connection travel time is reduced to less than four hours. The established connection was the last project in the programme *Verkehrsprojekt Deutsche Einheit* which attempted to integrate the traffic infrastructure of former East- and West Germany after its reunification in 1989 (Nauta, 2017). This enables HST to compete against air travel between the two cities. In the light of this debate this research aims at studying the relation between domestic HST connections and airlines of the German network. This will be done from the perspective of the spatial structure of urban regions.

1.1 Project framework

This research consists of a comparative case study on the long-distance passenger travel between two urban regions in Germany. It seeks to identify possible relations between the intermodal competition and the urban spatial structure of the urban regions connected by these transportation modes. Therefore, it will only focus on the relation of mass transit services, which means that the car is not included. The reason for this is that the car is a form of private transport which consists of different market characteristics than the public modes HST and airlines. By adopting an environmental perspective this study only focuses on the supply of HST and airlines rather than the demand of passengers for these services.

1.2 Research objective

The aim of this study is to research the extent to which the spatial structure of urban regions has a relationship with intermodal competition between HST and airlines between urban regions in Germany that are served by both modes of transportation. By defining the characteristics of urban spatial structures, one can investigate whether there is a relation between the current HST and airline supply for the urban region. Since urban regions differ in structure and will be compared it is expected that the elements of urban spatial structure which are supporting the supply of HST and air services will be identified.

1.3 Scientific relevance

Because of the growing investments in high-speed rail, the concept of intermodal competition has gained plenty attention in academic literature on transport planning (Behrens & Pels, 2012). The perspective of the urban spatial structure is relevant to this paradigm because HST is mainly focused on connecting city-centres. Following the study of Dobruszkes (2011) this reopens the discussion in urban planning whether HST should serve compact cities or suburbs and major agglomerations as well, in order to compete with air travel.

1.4 Research questions

This paragraph presents sub-questions that function as building-blocks for answering the main research question. Since the questions are rather methodological and require answers in sequential order they will be answered throughout this paper. Therefore, for each sub-question is argued how this will help to answer the main research question, as well as references to the sections in which they are answered.

1.4.1 Main research question

To what extent do spatial characteristics of urban regions influence the intermodal competition between high-speed trains (HST) and airlines for domestic long-distance passenger travel based on two cases in Germany?

1.4.2 Sub-questions

This paragraph elaborates on the sub-questions. For each sub-question is argued why and how it supports answering the main research question.

1 Which spatial characteristics of urban regions influence the mode choice in domestic long-distance passenger transport?

By reviewing the scientific literature, the main spatial characteristics of the case regions can be identified. Subsequently, they will be measured for two case regions to determine their extent of influence (refer to par. 2.5).

2 What characterises intermodal competition between HST and airlines?

The characteristics of intermodal competition provide insight in its economic context to whom urban spatial structure is subject (refer to par. 2.5).

3 Which variables are relevant for measuring the competitiveness of both modes of transportation?

This sub-question seeks to identify the spectrum of variables that are influencing intermodal competition, so the relative influence of urban spatial structure can be defined (refer to par. 2.5).

4 Which urban regions in Germany are interconnected by both HST and airline services and what are their spatial characteristics concerning question 1?

The answer to this sub-question provides a reasoned basis for selecting the cases to be studied (refer to par 3.5).

5 What are the data concerning the variables found by answering question 3 for both modes of transportation between urban regions in Germany?

This sub-question aims at operationalising the variables adapted from the literature study and operationalising them to find applicable data (refer to par. 3.5).

6 *What are the relations between spatial characteristics of urban regions and the comparative data for HST and airlines within Germany?*

This sub-question aims at understanding comparative data for HST and airlines can be used to draw relation with spatial characteristics of urban regions (refer to par. 3.5)

2. Literature review

The aim of the literature review as elaborated in this chapter is to identify the central academic concepts for relating urban spatial structure and the interaction between high-speed transportation modes in long-distance travel. In the first section, literature on urban systems has been investigated in order to identify the characteristics of urban spatial structure. The second part studies the context in which the interaction between long-distance travel options of HST and airlines occurs. Third, urban spatial structure and long-distance modal interaction are linked. The chapter is concluded by the description of the conceptual model and answers to the three first research questions.

2.1 Urban spatial structure

2.1.1 The network society

The theoretical basis for this research is the theory on the network society of Manuel Castells (1996). Two central concepts in this theory are the 'space of places' and the 'space of flows'. The space of places is the physical expression of society consisting of a certain symbolic meaning. Following Castells (1996) society is constructed around flows, being flows of capital, information, technology, organisational interaction, images, sounds and symbols. The network society is shaped by new spatial form characteristics called the 'space of flows'. This concept describes the material organisation of time-sharing social practices that work through flows. In other words: it is based upon a network that link specific places with common social, cultural, physical and functional characteristics (Albrechts & Coppens, 2003). In such networks a place does not exist by itself but is defined by the interchange of flows within the network. Places with strategically important functions which build upon locality-based activities and organisations around a key function in the network are called 'nodes' (Castells, 1996).

2.1.2 Interurban relations

The global process of urbanisation leads to a concentration of population and activities in urban and metropolitan areas. In addition to metropolitan areas there is an emergence of metropolitan regions which include several metropolitan areas in one unity (Castells, 2002). The metropolitan region is shaped by a polycentric structure with different hierarchies between its centres, which leads to a decentralisation of activities, residential areas and services with mixed land uses. The spatial form consists of multiple cities in a disrupted rural space, which includes urbanised areas, agricultural land, open space and highly dense residential areas (Castells, 2010). Such regions can connect people and activities over a large space in terms of (tele)communication and transportation systems. They are becoming the core of Europe and are thereby strongly interlinked (Castells, 2002).

In order to understand the interlinkages between urban places a 'Central Flow Theory' was developed to be complementary to the classic Central Place Theory of Christaller (Taylor, Hoyler, & Verbruggen, 2010). The emphasis of central place thinking lies on the hierarchical or vertical relations between urban places, in which the functionality of an urban place differs from others. However, such hierarchical thinking encompasses only partially the understanding intercity relations. Taylor et al. (2010) make a distinction between 'town-ness' and 'city-ness' to describe the difference between local hierarchical relations and interurban relations that stretch beyond the hinterland. Town-ness encompasses the external vertical relations that link an urban place to its hinterland. However, the process of intercity relations is horizontal and goes beyond the hinterland. The classic work of B. Berry (1964) describes city-networks as: 'cities as systems within systems of cities', which makes this phenomenon more clear. The area of research that studies these urban external relations is referred to as macro transport geography. Within this field long-distance travel via rail and air is being discussed.

2.1.3 Exploring the concept of urban regions/regional urban systems

The classic central-place model of Walter Christaller aimed at describing city-hinterland relations in rural areas. Later the model was also applied at higher scales, such as the European continent. This idea of such hierarchical urban systems has an emphasis on mono-centricity which is in the light of contemporary urban structures has problems to explain reality. In contemporary urban systems, a more polycentric spatial organisation of metropolitan areas is being observed in which hierarchy is becoming a less important feature of urban systems (Burger & Meijers, 2012). The spatial structure of the urban can be studied at various scales. Due to innovations in transport, communication technologies and economic prosperity, the spatial configuration of 'the city' has become more complex. New forms of economic activities of companies and the social activities of individuals have extended spatially. This led to the existence of centres which specialise in economic, social and cultural functions (Limtanakool, Dijst, & Schwanen, 2007). The function of a spatial entity within urban systems is therefore scale-dependent. Locally it serves as a place for daily activity for individuals, while at the regional, national or global level it functions as a node within each respective urban system (Antikainen, 2005). Except locally, the monocentric model has therefore become obsolete since there is a high degree of (physical) interaction between these centres (Limtanakool et al., 2007).

Although urban systems vary substantially in terms of geographical and socioeconomic characteristics, both morphological (urban form) and functional (urban spatial structure) areas consist of two structuring elements: nodes and linkages (Rodrigue, Comtois, & Slack, 2017). Nodes are centres within urban systems in terms of functionality (economic activities) and accessibility (transportation network). Burger en Meijers (2012) refer to such nodes as 'centres' within urban systems and make a distinction between the nodality and centrality. The nodality can be defined as the size and the range of socio-economic activities offered by the centre. The centrality of a centre stands for its relative importance and contribution to urban functions, being the provision of goods, services and jobs, which are demanded by its inhabitants. Nodes are being connected linkages, which are the infrastructure to node-supporting flows. In the framework of this research HST and airlines are considered to be such linkages within (inter)national urban systems, as well as the supporting regional transportation infrastructure which defines the accessibility of their terminals.

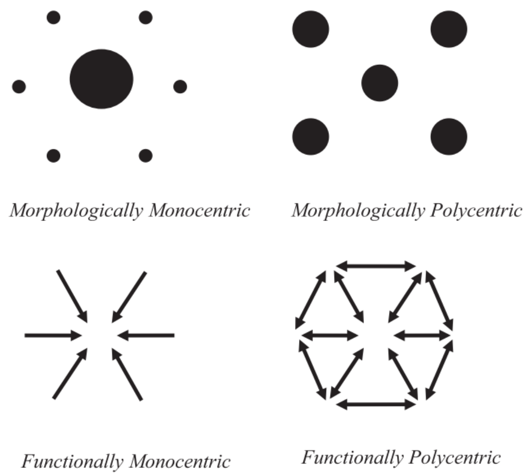

Figure 1 The morphology and functionality of urban systems according to Burger and Meijers (2012).

Building on the analogy of nodality and centrality, two approaches to measure the spatial structure of systems can be distinguished: morphological and functional polycentricity (refer to fig. 1). Morphological polycentricity is related to the spatial form, while functional polycentricity refers to the patterns of activity within an urban region. Burger and Meijers (2012) conducted a case study on The Netherlands to examine these forms of polycentricity. They demonstrate that most regions are relatively more functionally polycentric than morphological polycentric. It is concluded that the greater the dominance of functional polycentricity, the greater the degree to which the principal city is self-sufficient – can build on its own labour and consumer market – and the larger the size of this principal city.

2.1.4 Towards Functional Urban Areas (FUA)

Taking the literature discussed above in account, one could argue that the spatial scope of regional urban systems is to the utmost extent defined by its functionality. Cities are no longer morphological entities with clear and detectable borders. Contemporary 'cities' are functional urban regions incorporating larger areas around the central city. This spatial shift is grounded in the argumentation from Castells (1996) introducing the 'space of flows' as a concept that describes the urban form to be constituted by a functional network of communities. These may be physically or linked or separated but are connected through multiple forms of daily mobility, such as commuter flows (Vasanen, 2012).

Academic literature provides multiple methodologies to measure the scope of an urban region in which spatial units are functionally interlinked. The European Spatial Planning Observation Network (ESPON) has proposed a model in which core municipalities and adjacent commuting areas together form a Functional Urban Area (FUA) to compare them over measurable standards (ESPON, 2005). Although there is no consensus about the exact definition, FUAs can basically be defined as travel-to-work areas: agglomerations of work places that attract work forces from surrounding areas (Antikainen, 2005). At the level of functional regions, commuter flows are more widespread than other interdependencies, such as customer flows for shops and cultural institutions (Bundesinstitut für Bau-, n.d.). Thereby, commuter flows can be seen as a proxy for the spatial scope of functional urban regions. Even though this dependency on commuter flows, municipalities incorporated obviously share more functionalities. At higher scale levels FUAS can be compared over their functional specialisations. Therefore, ESPON (2005) has distinguished six functions, being population, transport, tourism, manufacturing, knowledge and decision-making power in both the private and public sector.

2.2 The interaction between HST and airlines in long-distance travel

2.2.1 An introduction to long-distance travel

Long-distance travel can be defined as the flows between urban regions. Following the definition of Limtanakool et al. (2007) such regions are situated at a minimum of 100 kilometres from each other. The dominant transportation mode for this travel is the aircraft. However, some cases have proven that HST might offer a supplementary or even substitutionary role in the long-distance travel system. For instance, the study of Behrens and Pels (2012) shows that in the Paris-London corridor (approximately 450 km) that frequency, travel time and distance to terminals are the main determinants of travel behaviour. In the case of air travel, in-vehicle travel time and distance to terminals cannot easily be improved. The study discovered that for this reason, airlines which were not able to maximise profits regarding a schedule frequency competitive to HST left the market.

Demand in urban mobility partially depends on the transportation modes available and is therefore supply-dependent (Bento, Cropper, & Mushfiq Mobarak, 2005). However, such a study has not been conducted for long-distance travel. The question arises whether passengers are willing to shift from the aircraft to the HST. The global study of Schafer and Victor (2000) demonstrates over historical patterns that the share of money spent by individuals on travelling is constant: a rising income leads to a rising demand for mobility. Another constant factor is the share of time spent for travel on average. Therefore, the common phenomenon observed globally is that individuals shift from slower to faster modes as income and the demand for mobility increase. Deviation from this phenomenon might take place because of the availability of certain infrastructures, which are reflected by population density, policies and personal preferences.

However, over the long-term transport systems behave in deterministic patterns since the natural selection of transport modes is based on the speed of its service. Long-distance mobility therefore depends heavily on access to high-speed modes. Areas with low population densities where travelling to nodes in the high-speed transportation system is time-extensive, will for that reason maintain (Schafer & Victor, 2000).

2.2.2 Definitions of intermodal competition and cooperation

HST and air transport are the key modes of long-distance transportation for travelling between urban regions. HST normally runs at an average speed of 250 kilometres per hour and is therefore considered competitive for air transportation on journeys ranging between 160 and 800 km (Chen, 2017). Next to these characteristics high seat capacity and frequency are recommended (Givoni, 2006). In general, the interaction between HST and aircraft consists of both competition and cooperation (Rodrigue et al., 2017). Intermodal competition relates to the possible substitution of the HST over airlines or vice versa. According to several studies HST has proven to be a viable substitute for air travel by offering comparable or shorter travel times. Besides, given the fact HST terminals are often located in city-centres it offers direct accessibility to core business activities or other urban functions, in contrast to most airports which are often situated in the outskirts of cities (Givoni & Banister, 2007; Rodrigue et al., 2017). In intermodal cooperation however, HST only plays a partial substitutive or even supplementary role in connecting domestic travel with air transportation (Albalate, Bel, & Fageda, 2015). In the light of hub-and-spoke systems, which is widely used in the airline industry, a better integration between passenger rail and air transportation might enable substitution for the more environment-friendly HST. As well as the possibility to use satellite airport terminals (Rodrigue et al., 2017). In some cases, air carriers (Lufthansa, Air-France) are offering tickets in which a segment of the journey is covered by an HST connection. HST stations at airports, such as in the cases of Frankfurt or Amsterdam, therefore enable to connect long-distance air travel with regional accessibility via HST (Albalate et al., 2015; Chiambaretto, 2013; Givoni & Banister, 2007).

2.2.3 New emerging network structures

Airlines manage different network structures. Generally, they either develop a hub- and-spoke system or a point-to-point network. Legacy carriers prefer the hub-and-spoke approach, operating from large hub-airports connections to other hubs and regional feeder airports are being established. Feeding flights bring passengers to a hub airport from which a connecting to another flight to an international destination. On the contrary, low-cost airlines have adopted a point-to-point strategy by connecting regional airports directly (Chiambaretto, 2013). This distinction has been further polarised by the liberalisation of air transport in the period from 1986 to 1997, which encouraged a growth in geographical diversity in terms of supply – more city-pairs are served – and the development of low-cost air connections (Dobruszkes, Lennert, & Van Hamme, 2011).

The supply or feeder function within hub-and-spoke systems might be substituted by HST if it provides better and faster transport possibilities (Givoni & Banister, 2007). Airlines can integrate services with HST operator and offer train alternatives for feeder flights so the scarce capacity at hub airports can be freed. However, in regions having access to multiple airports which are connected by HST, catchment areas are being stretched substantially and will lead to increasing competition between airports (Terpstra & Lijesen, 2015). The geographical range of catchment area of hub airport – from which the feeder flights towards and from regional airports are be connected – generally is less than 1000-1500 km (Chiambaretto, 2013). When available, HST can cover a substantial part of this catchment area. This might lead to problematic situations for regional feeder airports which are not connected to the HST network and therefore are therefore vulnerable for substitution. Figure 2 shows the emerging tendency in which the hub-and-spoke system in the airline industry is being transformed. The main air carriers connect the larger hubs in the network, while HST is to replace the feeder function from regional airports. Low-cost carriers provide flights between regional or secondary airports.

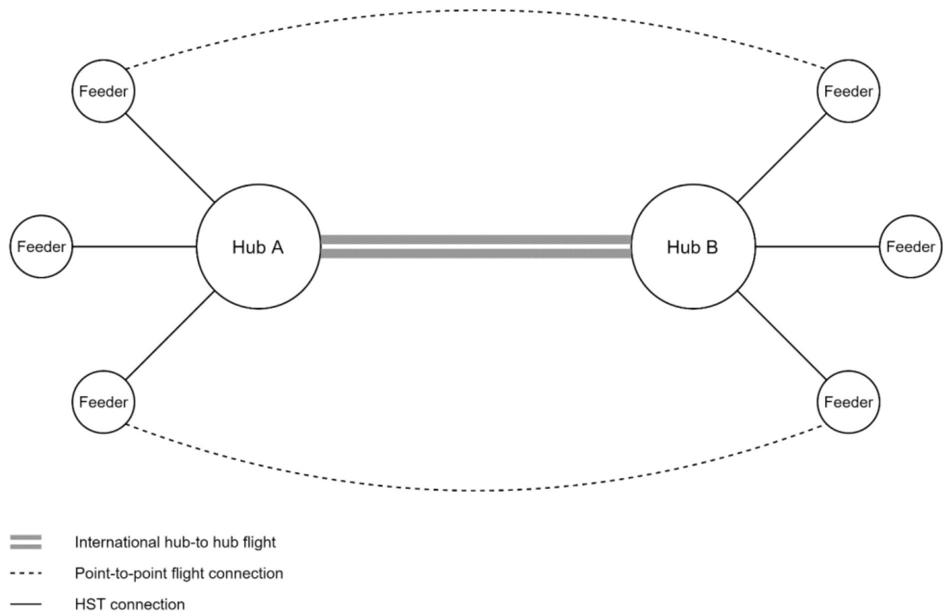

Figure 2 Own elaboration of literature on airport catchment areas.

European transport policy supports the substitution of aviation by HST for journeys of up to 3-4 hours, while regional aviation is being promoted for peripheral areas that lack critical mass of being served by HST. However, Givoni (2006) argues that HST is only viable between urban agglomerations with over one million population, with cities located at approximately 200 km intervals to consolidate speed advantages. In summary, the dualism of competition and cooperation might lead a further increase of core (European) transport hubs – multimodal terminals of air and HST – that offer global connectivity (Spiekermann et al., 2015). To be an effective (partial) substitute to the aircraft needs to include stops at major airports in order to enhance the integration between HST and airline services (Givoni, 2006).

2.2.4 Terminal accessibility

One of the most important advantages of HST is its accessibility to terminals in comparison to air transport. Airports are commonly located several kilometres away from city-centres, in contrast to HST stations which take a central position in the regional public transit network and are often situated in densely populated urban cores (Martín et al., 2014). Therefore, the spatial competitiveness of both types of terminals is consequently determined by its access time, which depends on the mode of transportation. This is explained by Martín et al. who demonstrate in their study from 2014 that generally car accessibility increases the competitiveness of airports, while public transport accessibility promotes the competitiveness of HST stations. Travellers tend to choose a transport alternative son the base of the best service and minimum cost.

Based on this assumption, total travel time is a variable shaping the intermodal competition not to be neglected: when total travel time increases, HST market share falls in comparison with other modes (Dobruszkes, 2011). Travel time consists of access, egress, waiting and in-vehicle time. HST is dominant in terms of access, egress and waiting times, while air travel generally offers shorter in-vehicle times (Martín et al., 2014). Brons, Givoni and Rietveld (2009) add to the discussion that the frequency of the public transport service to the HST station appears to have more impact on reducing the travel time than reducing the in-vehicle time of the journey. The absolute distance to HST stations is a less important aspect in terms of the effect on rail use. Reducing the distance to the terminal relates to changes in the network and not the access to it. However, this might require large investments and might not improve the service level for the entire network (Brons et al., 2009).

2.2.5 The dynamics of catchment areas

The concept of catchment areas is defined as the area from which a transport terminal - whether it be an airport or train station - attracts its passengers (Rodrigue et al., 2017). Catchment areas vary in range according to their function within each respective network. The size and shape of the catchment area of an airport is influenced by three factors. The most important dimension is the available offer of services: direct or indirect accessible destinations, flight frequency (time schedules), ticket fares are shaping airport choice and therewith catchment areas (Dobruszkes et al., 2011; Terpstra & Lijesen, 2015). Second, the ground side accessibility of the terminal (refer to par. 2.2.4). At last, the characteristics of the passenger population which influences the demand by the purpose of its travels and is thus sensitive to price and time when choosing an airport (Dobruszkes et al., 2011).

In the case of HST-stations, academic literature does not broadly cover the concept of catchment areas since it mainly focusses on the propensity of conventional train use. Like the determining factors of airport catchment, the likeliness of choosing the train as transportation mode consists of roughly the similar three elements: the level and quality of the rail service itself, its accessibility and the characteristics of the area and population served (Brons et al., 2009).

2.2.6 Transport effects of HST and air travel

Improvements in long-distance passenger travel efficiency offer a solid argument in the climate debate. In Germany – the hosting nation of the case study for this thesis – long-distance passenger travel is responsible for more than 50 percent of the total climate impact caused by transportation (Reichert & Holz-rau, 2014). As academic literature often claims, Givoni demonstrates in his study from 2007 that shifting services from the aircraft to HST will lead to environmental benefits in terms of reduced climate change, air and noise pollution.

The work of Givoni (2006) indicates four positive transport effects of HST-services. At first, the main reason for constructing HST in the cases of Shinkansen in Japan and the TGV in France was to increase route capacity. HST lines increase the capacity on specific route since they form a supplement to existing lines and free the capacity of the conventional network for both freight and regional passenger services. Second, the reduction of travel time for passengers is an important effect in terms of cutting travel time by the average speed that can be achieved due to the number of stops and speed restrictions along the route. The third effect encompasses the construction of HST which can only be attractive on high-demand routes. Therefore, HST connections are mainly established between city-centres. Cities with dense and dominant city-centres, for instance in terms of population and employment are more attractive to HST, than cities with a more dispersed nature. At last, shorter travel times and improved travelling conditions lead to changes in the modal share of HST and generate new demand.

2.3 Linking the concepts: urban spatial structure related to long-distance travel

Little attention has been paid to the relation between urban spatial structure and long-distance travel in academic literature. Therefore, this is synthesis aims to cover this gap.

Urban spatial structure imposes implications for HST competitiveness because HST has proved to perform best in populous and dense urban centres (Zhong, Bel, & Warner, 2014). While inter-metropolitan air transport provides direct links and therefore has little effect on the accessibility of urban populations in-between, HST improves the interconnectivity between metropolitan areas and intermediate cities (Ureña, Menerault, & Garmendia, 2009). For transport policy making in polycentric regions this leads to a difficult consideration: whether to serve suburban populations by providing several stops throughout the HSL or limit the number of stations to ensure the high speed and frequency advantages HST comes with (Givoni, 2006). In the second case, HST is accompanied with the 'tunnel-effect' in which there is relatively small number of stations along the HSL connected. In the overall rail network perspective, this results in the reduction of accessibility and reduced position in the competition with other (local) transport modes (Sánchez-Mateos & Givoni, 2009). Besides, investments in HST in low dense populated areas often lack profitability, due to a lack of potential travellers. Therefore, urban regions characterised by a dispersed spatial structure are less attractive to HST station development (Zhong et al., 2014).

Regarding the relation of urban spatial structures and travel demand academic literature provides in particular insights in terms of commuter travel and these variables are positively related (Bento et al., 2005). However, a study on the impact of these structures on long-distance travel is largely unexplored. Many studies have been conducted on the relation between urban form and travel. The study of Holz-Rau, Scheiner and Sicks from 2014 argues that high-density populated regions reduce the distance travelled due to the proximity to urban functions. This is however, in terms of for instance transport emission impacts, counter-balanced by the fact that residents of urban areas undertake more long-distance trips. The research considers three explanations for this phenomenon. First, it is assumed that cities function as nodes within the nation and global urban system. Second, this place in urban systems comes often with a better accessibility to long-distance travel infrastructure which may encourage people to undertake more long-distance trips. Third, the urban lifestyle of individuals is considered. Individuals have more dispersed social networks and have a stronger need to 'escape-trips from the city'.

Another influencing factor on the mode-use in long-distance travel is the organisation of the local transportation-system. A case study on the Madrid-Barcelona corridor compared the competitiveness of air travel and HST on this trajectory (Martín et al., 2014). The study showed that from a spatial perspective access time to terminals, whether it be an airport or HST-station, can be an explanation for mode-choice. Since this is depending on the chosen access mode, the access to a suburban rail network station increases the competitiveness of the HST. On the contrary, car accessibility encourages the competitiveness of air travel. Transport policy strategies to improve local accessibility transport terminals might therefore influence the market shares of competing modes in this corridor.

The study of Dobruszkes (2011) demonstrates that in studying multimodal competition geographical features of the cities connected, and the spatial distribution of economic activities and populations that generate (international) flows in particular, should be taken into account. Not everyone travels between city-centres, making it not necessary that everyone will travel per HST. From an environmental perspective HST has a negative impact including local air and noise pollution, land take and climate change. However, HST development is usually perceived in a positive way since its environmental impact is less than other modes of transportation, especially the aircraft (Givoni, 2006).

2.4 Conceptual framework

The link between a long-distance travel mode and urban spatial structure is the catchment area of this mode. However, comparing two means of transportation for long-distance travel is complicated for two reasons. First of all, both HST station and airports have different catchment areas since terminals may have different functions. Especially airports which sometimes have a hub function within a broader network. Secondly, empirical studies concerning the spatial scope of catchment areas are lacking. A possible solution is proposed by Dobruszkes et al. (2011). In this study it is shown FUA can be used as a practical proxy to analyse a catchment area. Referring to section 2.1.3, urban spatial structure is defined by its functionality rather than its morphology. This also supports the choice for FUA as unit of analysis.

Section 2.2.5 shows that catchment areas are described by three elements, being the service of the travel mode, terminal accessibility and characteristics of the passenger population (Brons et al., 2009; Dobruszkes et al., 2011).

The urban spatial structure consists of different municipalities which are spatially distributed. Municipalities are selected because they are the smallest statistical units available for data collection. The passenger population of each of these municipalities can be described by five features: population, population density, employment, income and tourism. Population and population density are important variables for defining the viability of HST-stations. They are closely related to the size and shape of catchment areas (Dobruszkes et al., 2011; Terpstra & Lijesen, 2015). Population density indicates the concentration of potential riders whereas, whereas total population represents the critical mass needed for both the HST station and the airport (Zhong et al., 2014). Referring to par. 2.3, business is – next to tourism – the main trip motive in long-distance travel. The spatial distribution of employment within the urban spatial structure gives insight in the locations with high levels of business activity. Therefore, the main interregional interaction is assumed to take place between core business locations. In the case of tourism, places that are characterised by high levels of tourist overnight stays help to get an understanding of their relative positions within the urban spatial structure. Both variables are considered to be important destinations in long-distance travel. Finally, referring to 2.2.1, income is positively related to long-distance travel demand. Together with employment levels these locations will be the most important in terms of long-distance travel origins.

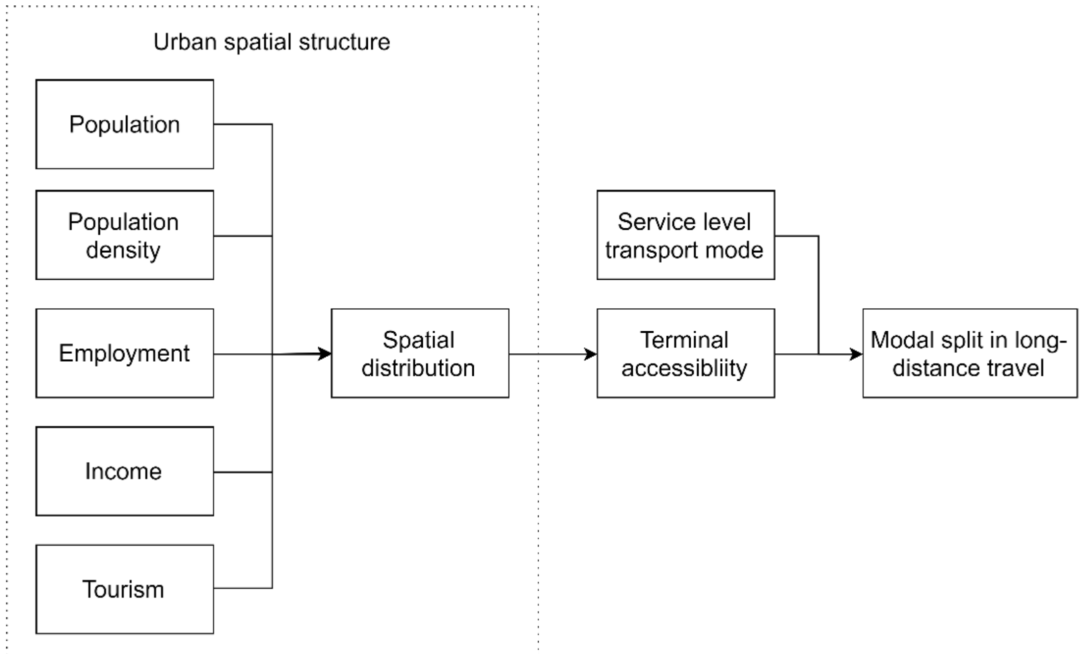

Figure 3 Conceptual model

Terminal accessibility is determined by the relative position of the spatial unit to the HST stations or airports by car or public transport (refer to section **Error! Reference source not found.** for more details). This relative position is equal to the access time from the potential origin (municipality) towards the destination (HST station or airport) (Martín et al., 2014). The purpose of analysing relative positions is to determine the transportation mode that is potentially being favoured. The above described framework is visualised in figure 3.

2.5 Reflection

The aim of the literature review as elaborated in this chapter was to identify the central academic concepts for relating urban spatial structure and the interaction between high-speed transportation modes in long-distance travel. In the first section, literature on urban systems has been investigated in order to identify the spatial characteristics of urban regions that influence the mode choice between HST and airlines. This has resulted in an answer to the first research sub-question:

Which spatial characteristics of urban regions influence the mode choice in domestic long-distance passenger transport?

To investigate the spatial characteristics of urban regions the concept of urban spatial structure at the scale of the region has been used. This concept was extracted from the literature review and refers to functional structure of urban regions. Based on several studies that investigated the spatial determinants of travel demand, five variables were proposed that shape the long-distance travel demand. These being population, population density, employment, income and tourism.

The remainder of the review aimed at sketching a framework in which the modal interaction between HST and airlines takes place, related to the second research question:

What characterises intermodal competition between HST and airlines?

Intermodal competition is particularly a subject within transport economics. It relates to the market functioning of – in this case – two competing suppliers with distinct characteristics. However, the spatial manifestation of these markets is articulated by catchment areas. These are the spatial dimensions of the market potential of both the HST station and the airport terminal. In order to compare the competitiveness of both modes the determinants of the size and shape of catchment areas are selected as defining characteristics of intermodal competition. These are for each respective transport mode its service level, the accessibility of its terminal and the characteristics of the population served by the terminal: urban spatial structure variables.

Finally, the third research question could be answered:

Which variables are relevant for measuring the competitiveness of both modes of transportation?

Urban spatial structure is a constant factor for both transportation modes. The remainder – being terminal accessibility and service level – are therefore relevant for measuring the competitiveness of the modes at this spatial scale. The service level consists of total travel time, frequency and seat capacity. Terminal accessibility is measured by travel time to the HST station and the airport by car and public transport.

3. Research design and methodology

The chapter elaborates on the design of the research and elaborates on the methodologies used. The research philosophy and strategy (par. 5.1 and 5.2) provide insights in the rationale and application of the methods used. The latter is divided into a description of how the data was collected (par. 5.3), while par. 3.4 focuses on how the data was processing using different statistical methods. In conclusion, an answer is given to the three remaining research questions (par. 3.5).

3.1 Research philosophy

The issue of mode-choice in long-distance travel is complex due to the large scale at which it needs to be studied as well as the different orientations one may use to analyse it. This study analyses the discourse from an urban spatial structure perspective and aims at seeking empirical relations that might serve as starting point for future planning practices. Næss (2015) mentions four reasons conditions for spatial planning to be possible and meaningful. First, urban spatial structure needs to have an effect on the people's behaviour. Since this study investigates the relationship between urban spatial structure and long-distance mobility this criterium is met. Second, it must be possible to change people's behaviour by developing these structures. Third, it must be probable to assess the impact planning solutions so lessons can be learned for future practice. Finally, since spatial development is subject to social, economic, environmental and cultural contexts an interdisciplinary approach is needed to develop well-founded strategies.

Traditionally, in the subfield of transportation planning approaches which are grounded in the positivist philosophy dominate (Willson, 2001). Positivism depends quantifiable data that are generally used to perform statistical analyses. Another stream within transportation planning is represented by post-structuralist thinking. This school of thought takes the social context of transportation planning activities – by performing for instance qualitative discourse analyses – as the basis of analysis (Willson, 2001). However, both approaches neglect certain parts of reality by either predominantly interpreting statistics (positivism) or the more subjective interpretation of societal discourses (post-structuralism). In respond to this, the paradigm of critical realism seems to best fit the purpose of this research. This research philosophy offers a basis for researching causal relationships between social conditions, urban spatial structures and the actions of agents. Critical realism can basically be seen as the medium between quantitative positivist approaches and post-structuralist context driven approaches (Næss, 2015).

3.2 Research strategy

The choice for an applicable strategy for answering the main research question is based on the step-by-step approach for desk research by Verschuren and Doorewaard (2010, pp. 194–201). The most important reason for choosing desk research is to ensure the feasibility of the research given the spatial scope and the fact that the case regions are in Germany.

Therefore, the choice between an in-depth or comprehensive orientation of the research needed to be made. Since the objective focuses on identifying the extent of the influence of urban spatial structure on intermodal competition a comprehensive strategy is preferred to cover the breadth of the subject. The study can be characterised by as an embedded case study, encompassing two units of analysis – urban regions – within one case which represents the intermodal competition perspective (Yin, 2003).

In terms of methods, a quantitative approached was preferred, so the case regions can be equally compared. However, considering the critical realism philosophy as discussed in par. 4.1., quantitative methods will be followed by a critical review of the findings in relation to higher level-concepts that function as the basis for this research (par. 4.4).

The research process is started with a literature review that is conducted to encounter the main elements of urban spatial structure and the market characteristics of the long-distance travel market. Its findings are organised in a literature matrix (appendix A). The main elements derived from this review are the basis for the variables. Subsequently, the main elements have been operationalised and applicable data is collected from various sources (par. 3.3). This means that a deductive approach is used as secondary data is rearranged and analysed from the perspective of this research project (Verschuren & Doorewaard, 2010, pp. 194–201). Finally, multiple statistical analyses are performed, which are elaborated in par. 3.4).

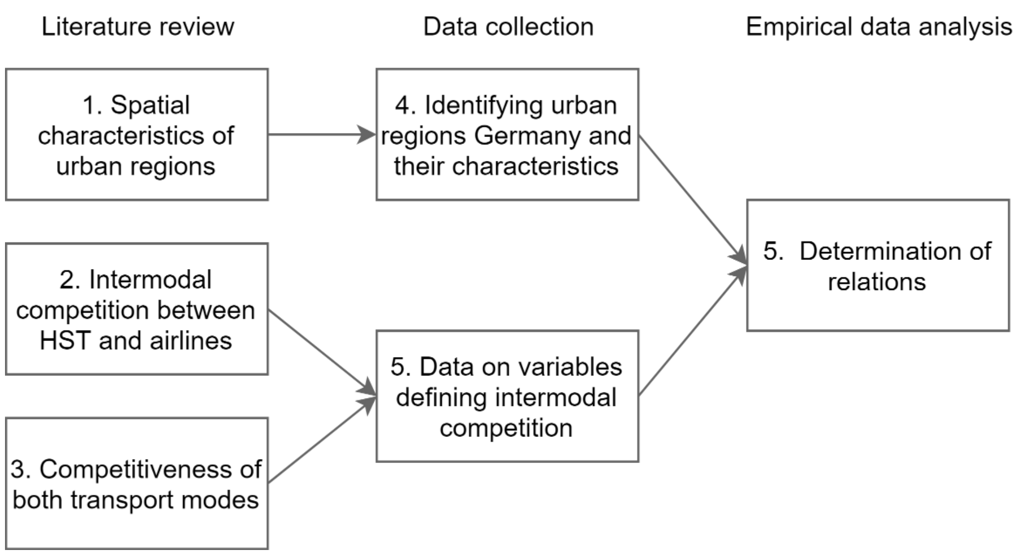

Figure 4 Overview of the coherence between the different research sub-questions

The three stages and their corresponding research questions schematically (refer to par. 1.4) are visualised in figure 4 to show the coherence between them and to give an impression on how the main research question will be answered.

3.3 Data collection

3.3.1 Case selection

This study consists of two cases which will be studied both comparatively and as an overarching issue (city-pair). The urban regions of Berlin and München have been included in the research sample since both are interconnected by a direct HST-connection and a direct airline connection. The second criterium encompasses the competitive distance of HST and air transportation being that the urban regions are located between 160 and 800 kilometres from each other (Chen, 2017). Since this research is highly dependent on the availability of applicable data respecting the elements of urban spatial structure, the two case regions are located within the same nation-state. From a practical perspective it can be argued that the two regions are covered by German statistical bureaus which enhances their comparability. Content wise, this offers possibilities to examine the position and the interactions between the two regions within the national urban system of Germany.

To assess the functionality of the two case regions, their spatial scope needs to be defined. This will be done on the level of municipalities to extract more detailed characteristics from a spatial perspective. Therewith, these are the smallest statistical units of analysis available on the scale of FUAs. Following the standards of ESPON, municipalities are defined as LAU2-regions. However, since there is no data available on the LAU2-regions incorporated in FUAs, municipality data from the Federal Office for Building and Regional Planning (BBSR) in Germany used. BBSR has defined a statistical unit called *Großstadtregion*, which corresponds with the definition of FUA. The municipalities of Berlin and München are subdivided into *Stadtbezirken*, because their population size is significantly larger than the other municipalities. Furthermore, since HST stations areas are located in high density settlements it is desirable to perform a more detailed analysis on smaller units. For the remainder of this research municipalities and Stadtbezirken will be referred to as spatial units.

The Großstadtregion consists of one or more urban cores and their surrounding areas, which can be subdivided into four zones (Table 1). The interdependence between these areas is measured by the commuting movements between the location of residence and of employment. BBSR uses data from social insurance companies, which covers approximately 70% of the total amount of employees in these areas. This is considered to be representative for the daily patterns of interaction (Bundesinstitut für Bau-, n.d.).

Table 1 Overview of zones in a Großstadtregion (Bundesinstitut für Bau-, n.d.).

Zone	*Characteristics*
Core area	– Commuter surplus (outgoing commuters / incoming commuters = >1) – Population> 100,000 inhabitants – Main commuter flow does not come from neighbouring centre
Complementary area	– Daily population density >500 – Commuter surplus or >50% of commuters commute to the centre
Narrow commuter area	– ≥50% of commuters commute to the centre or supplementary area
Wide commuter area	– 25-50% of commuters commute to the centre or supplementary area.

Figure 7 maps out the zones within the two Grossstadtregions. Although being comparable in size, the two regions are not equal in their classification of spatial units. The Grossstadtregions of Berlin consists of 109 spatial units with an average surface of 70.1 square kilometres, while München covers 285 spatial units of an average of 29.4 square kilometres each. This is not directly a shortcoming for the analysis but should however be considered when interpreting the data.

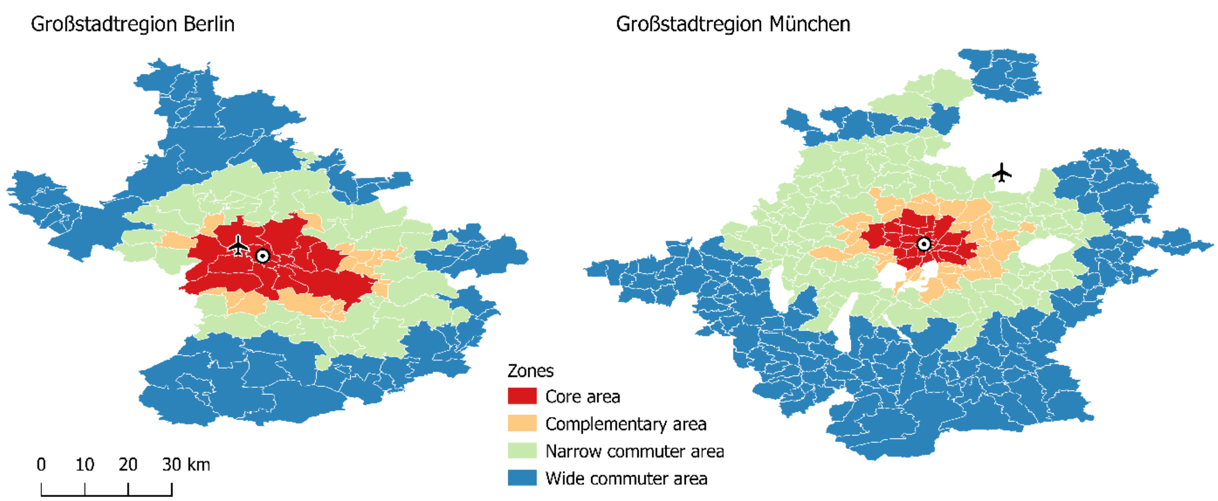

Figure 5 Zones within the Grossstadtregions of Berlin and München.

3.3.2 Operationalisation of urban spatial structure variables

This paragraph describes the operationalisation of urban spatial structure variables that – based on the conceptual framework in par. 2.4 – influence the mode-choice in long-distance travel. A schematic overview of the variables is provided in table 2.

Population and tourism data were obtained for 2016 which was the most recent year available. The population variable is reflected the number of inhabitants per spatial unit. The number of overnight stays per spatial unit is taken as a proxy for tourism. However, it can be argued that the relative differences between the spatial units for the data available provide sufficient insight in the spatial distribution of tourism. The last directly measured variable is employment, which is measured for the year 2015 by the number of employees registered for social insurances at their place work (spatial unit).

The indirectly measured variables are population density and income. Population density is simply the number of inhabitants per spatial unit weighed by its surface in square kilometres. However, for income the calculation is rather more difficult. Since there are no direct income data available on the municipality level in Germany, the indicator of taxable income is chosen as a proxy. Wage and income tax statistics provide an overview of the amount and distribution of income taxpayers are obliged to pay. In addition to solely tax considerations, studies and simulations of (spatial) income distribution are possible (Statistische Ämter des Bundes und der Länder, n.d.). To compare the municipalities within the Großstadtregions the total amount of taxable income per municipality has been divided by the number of taxpayers to calculate the average taxable income per taxpayer. However, the data cannot be retrieved on the level of Stadtbezirken. Therefore, the spatial distribution analysis of is limited to the complementary, narrow and wide commuter areas of the case regions.

Table 2 Overview of the variables of urban spatial structure, their units of measure and corresponding data sources.

Variable	*Units of measure*	*Year of measure*	*Source*
Population	Inhabitants per spatial unit	2016	– Regionaldatenbank Deutschland – Indikatorenatlas München – Statistik – Berlin Brandenburg
Population density	Inhabitants per square km	2016	– Regionaldatenbank Deutschland – Indikatorenatlas München – Statistik – Berlin Brandenburg
Employment	Number of employees at place of work registered for social security insurances per spatial unit	2015	– BBSR database – Indikatorenatlas München
Income	Taxable income per taxpayer per spatial unit	2015	– Regionaldatenbank Deutschland
Tourism	Overnight stays in 2016 per spatial unit	2016	– Regionaldatenbank Deutschland – (Schwarz, 2016)

3.3.3 Definition of HST stations and airport terminals

HST stations are characterised by two principal functions being its nodal and place value. Nodal value refers to the high levels of HST frequency and accessibility of populations within the regional network. The value of place represents the high density of economic functions, such as housing, business, shopping and education (Koning & Bonnier, 2015). Deutsche Bahn uses a comparable categorisation of train stations which can be divided into seven distinct categories[1]. This is according to their importance within the national rail system and the level of complementary economic functions. For this research, only the stations belonging to the first and most important category are included in the analysis. The analysis will provide insight in HST stations are operating at the München-Berlin route. Airport terminals are included in the analysis when flights between München and Berlin are offered. Therefore, Franz Josef Strauß airport (MUC) in München and Tegel (TXL) and Schönefeld airport (SXF) are considered in the analysis. Figure 7 provides a geographical overview of the HST stations and airports within the case regions.

[1] An overview of the categorisation of German railway stations is included in Appendix C.

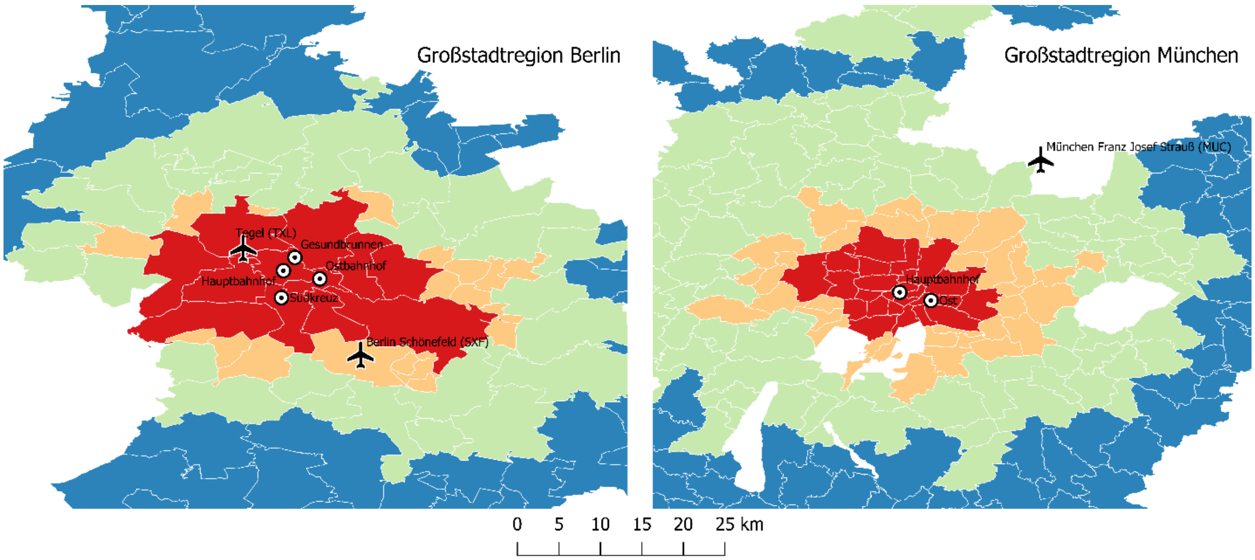

Figure 6 Zoomed in view on the geographical locations HST stations and airport terminals within the urban spatial structure of Berlin and München.

3.3.4 Terminal accessibility

Since this research focuses on the impact of urban spatial structure on the intermodal competition only, access and waiting time are considered when travel time is concerned. Based on this assumption terminal accessibility is selected as a variable in this study. Referring to 2.2.4, public transport and the car are the two main transport modes for travelling to and from long-distance terminals. For each of the municipalities in the Großstadtregion, travel times and distances by car from their centroids[2] to both the HST stations and airports have been calculated. Similar has been done in the case of public transit, but in this case only the travel time was considered. Using a Google Maps API, it was possible to automatically gather a travel time-distance matrix without entering the data one by one manually. It should be noted that for the München Großstadtregion, the access time by public transport was not calculated for all the spatial units. This is simply for the reason that – according to Google Maps – there were no optional connections available.

3.3.5 Service levels

The service levels for the HST and airlines are compared by three variables, being travel time, frequency and the number of seats. This is done by extracting data from online travel planners for week 24[3], which offers an indication of the operating schedules of both transportation modes. In the case of the HST, *Bayern Fahrplan* was used to obtain data for the route between Berlin and München. Using the web scraping tool *Instant Data Scraper* enabled me to automate this process. All route alternatives for the Intercity-Express (ICE) were considered. For each route alternative, Bayern Fahrplan calculated the travel times, while the sum of route alternatives represented the frequency. Finally, in order to discover the

[2] The central locations within an administrative spatial unit according to Google Maps.
[3] Week 24 lasts from 11 to 17 June 2018.

number of available seats per vehicle the seat capacity per ICE model running on the route were retrieved from *Datenbank Fernverkehr* (Datenbank Fernverkehr, n.d.).

The similar has been done for the flight schedule between the airports of Berlin Tegel (TXL) and München Franz Josef Strauß (MUC). Now, the online tool Flightradar24 was used to get insight in the travel times, frequency and aircraft models. However, to perform a more realistic comparative analysis in terms of travel time the average minimum check-in and check-out time as indicated by both BER and MUC airport is added to the calculation (table 3). The data on aircraft models was later used to identify the number of seats available via the online fleet showcase of Lufthansa (Lufthansa Group, n.d.).

3.4 Applied analytical methods

3.4.1 Spatial analysis

The mapping software QGIS enabled me to visually demonstrate the urban spatial structure of the Großstadtregions of München and Berlin. First, base maps were created by equalising the BBSR data of the Großstadtregions with shapefiles[4] of German spatial administrative units and merging them to two comparative maps of Berlin and München. Next, the data on the urban spatial structure variables as the accessibility data were linked to each respective spatial unit. Later the airports and HST station were added to the maps to visualise their relative distance to the urban spatial structure characteristics. The data in the choropleth maps were classified via the natural breaks (Jenks) method. This algorithm aims at finding natural groupings of data to create classes, meaning that there is a maximum variance between classes and least variance within each class. The rationale for using this classification is to show a clear difference between classes so the urban spatial structure variables where easier to compare and no manual classification had to be calibrated.

3.4.2 Potential accessibility calculations

The concept of potential accessibility adopts the theory of distance decay: the attraction of a destination increases with size and declines with distance, travel time or cost. The size of a destination can be represented by the urban spatial structure variables for this study, such as population size or income. Accessibility to populations is an indicator of market sizes for suppliers of goods and services (Spiekermann & Wegener, 2006). Therefore, this is considered to be suitable method for defining the potential market areas for the HST and the airport within the urban regions of München and Berlin.

Spatial interaction models assume that flows between origin and destination are a function of the attributes of these locations and the friction of distance between them (Rodrigue et al., 2017). The attraction of both HST stations and the airport terminal within the urban spatial structure are computed by the following equation:

[4] Geometric data (shapefiles) were adapted from the OpenStreetMap Plugin for QGIS.

$$T_j = \frac{W_j}{S_{ij}^2}$$

Whereby the level of interaction (T) of an HST or airport terminal with the other spatial units (j) within the urban spatial structure is measured by dividing the service level of the terminal by the friction of distance. The service level (W_j) is a product of the weekly frequency, travel time and available seats for each respective transportation mode[5]. Ticket prices were not considered in the analysis because of the high variability of airline ticket fares[6]. The friction of distance (S_{ij}) is the shortest travel time between the place of origin and the transport terminal, which can be either by car or public transport. The travel time is squared to reflect the growing friction of distance (Rodrigue et al., 2017). Since the model only accounts for the attributes of the terminal and not of the spatial units the interaction is not reciprocal.

For all spatial units the potential accessibility towards the HST station and airport has been calculated resulting in a potential accessibility index. In order to determine the potential mode choice within each spatial unit the indices were polarised from 0 (high airport potential) to 1 (high HST station potential). The following calculation is used when the airport has the highest potential accessibility index:

$$Potential\ accessibility\ index\ (airport) = 1 - \frac{airport\ index}{airport\ index\ +\ HST\ index}$$

If the highest potential accessibility favours the HST the following equation is used:

$$Potential\ accessibility\ index\ (HST) = \frac{HST\ index}{airport\ index\ +\ HST\ index}$$

The results of the potential accessibility analysis were later linked to the spatial data in QGIS. This enabled me to visually demonstrate the potential market attraction of both transportation terminals via maps (fig. 20)

3.5 Reflection

This chapter has elaborated on the research design and methodology, by discussing its research philosophy, strategy, approaches of data collection and applied analytical methods. The course of selecting applicable methods has resulted in answers to the fourth, fifth and sixth research sub-question.

4 Which urban regions in Germany are interconnected by both HST and airline services and what are their spatial characteristics concerning question 1?

This question was rather methodological with the purpose of choosing a city-pair that was suitable for analysis. Berlin and München and their in-between long-distance travel were chosen as the units of analysis. The rationale for this was the recent completion of the Verkehrsprojekt Deutsche Einheit which generated new attention for the subject and underpinned its societal relevance. Second, given the -X

[5] Refer to table 3 for an overview of the service levels per transportation mode.

[6] Ticket fares in the airline industry are subject to various variables shaping them, such as route competition, seasonal differences, seat demand and supply and varying fuel prices. Since the prices for HST tickets are more constant, a ticket fare comparison would only be useful when measured over a longer time period.

range requirement at which the HST is competitive to the aircraft should be met to make a good comparison as well as an established flight connection between the two urban regions. Finally, the accessibility of comparable data for the different units of analysis was needed to perform an appropriate analysis. Based on these assumptions, the Berlin-München case was selected for analysis. Their spatial characteristics have been thoroughly analysed in par. 4.2.

5 What are the data concerning the variables found by answering question 3 for both modes of transportation between urban regions in Germany?

This question has been approached from a supply-oriented perspective. The data concerning long-distance travel are based on the service schedules of the ICE and the airlines operating between Berlin and München.

6 What are the relations between spatial characteristics of urban regions and the comparative data for HST and airlines within Germany?

The relations between spatial characteristics of urban regions (urban spatial structure) and the data on the competitiveness of the HST and airlines (service levels per transport mode) are methodologically justified by two means. First, the terminal accessibility can be related to urban spatial structure by determining the percentage of the settlements within spatial units reached within a certain travel time range. Second, the potential accessibility analysis provides a gravity model through which the service levels of the HST station and the airport are weighed by their relative distance to the spatial units.

4. Results

In this chapter the results of the statistical analyses are presented for the regional urban spatial structures (4.2) of the Großstadtregions of Berlin and München as well as the intermediate travel via HST and the aircraft (par.4.1). Subsequently, the analysis on terminal accessibility provided insight in the competitiveness of access modes, access times per urban spatial structure variables and the potential accessibility of the transport terminals.

4.1 Intermodal competition in the Berlin-München market

4.1.1 An introduction to the Berlin-München route

The map depicted in figure 8 shows the weekly flights from Berlin and München to the other main airports in Germany. It can be noticed that the Berlin-München route is an important connection for both urban regions. After Frankfurt am Main – which is the most important hubs of air carrier Lufthansa – Berlin and München are the main destinations for each other in domestic air travel.

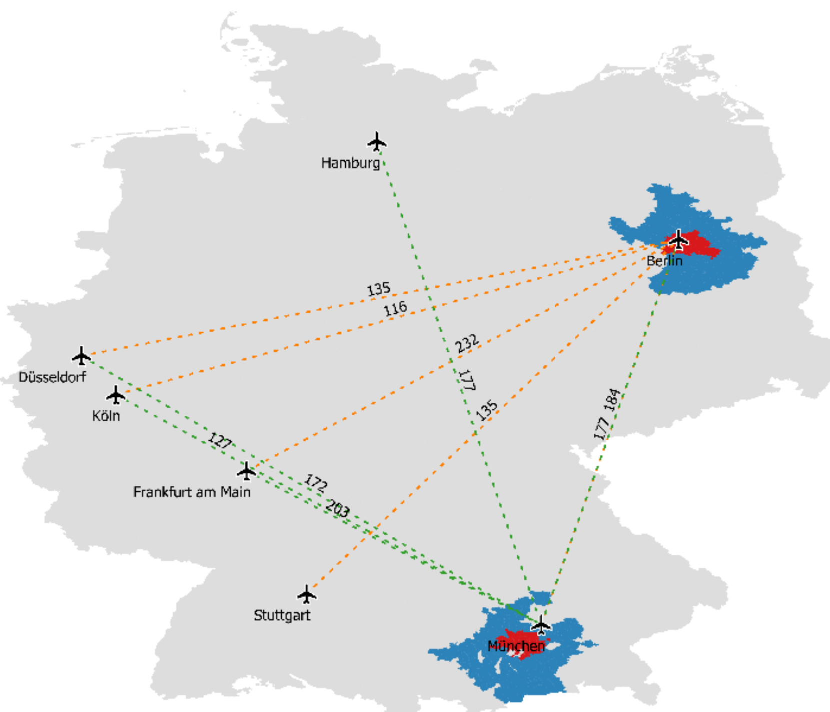

Figure 7 Domestic flights per week to the major German airports originating in Berlin and München (source: flightradar24.com., own elaboration).

The two air carriers operating on the trajectory between Berlin and München are EasyJet and Lufthansa. Lufthansa is the main operator since weekly they schedule 232 flights between Berlin and München resulting in a market share of 76%. The connection is part of its Network Airlines business segment which operates a multi-hub strategy. This strategy is gaining popularity due to the growth of network carriers (Burghouwt, 2013). MUC airport is one of the hubs of Lufthansa, next to Frankfurt, Wien and Zürich. From a conceptual perspective, the Berlin-München route can therefore considered to be a feeder-to-hub flight rather than a hub-to-hub flight (Chiambaretto, 2013). In Germany, Lufthansa has established partnerships to supplement flight plans, such as the Rail&Fly program in cooperation with Deutsche Bahn which allows passengers to travel to and from the airport as an extension of the journey (Lufthansa Group AG, 2018).

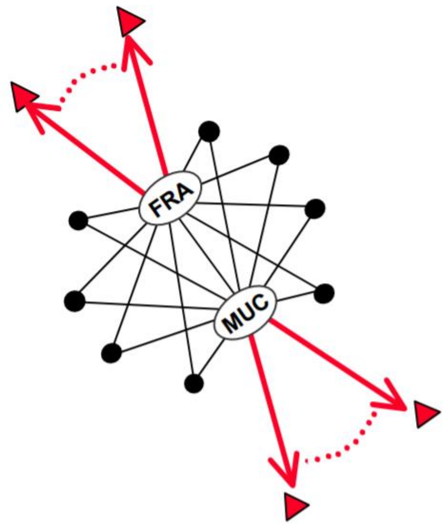

Figure 8 Multi-hub strategy operated by Lufthansa. FRA and MUC airport operate as global hubs within the regional network of Lufthansa (Garnadt, 2008).

The other operator in the air market is EasyJet, which covers with 75 weekly flights 24% of the market share. Their strategy is focused on developing strong positions at the key airports in Europe, which serve catchment areas that represent large economic markets. This is combined with high frequencies, attractive flight timings on high demand routes for both leisure and business travel. EasyJet strives to be competitive to both network airlines and charter carriers at the key airports. The structural cost advantage relative to these airlines allows to offer passengers more affordable fares. These cost advantages are established for three reasons. First, the configuration of their aircrafts enables a higher number of seats. Second – and in contrast to Lufthansa – EasyJet operates a point-to-point model which facilitates a higher load factor per aircraft. Third, the possession of a young and advantaged fleet deal reducing ownership and maintenance costs (Easyjet PLC, n.d.).

Figure 9 draws on the development of passengers and the number of seats travelling via air between Berlin and München in the period from 2002 to 2016. The figures represent the traffic volume in both directions. Obviously, the number of seats offered by air carriers is higher than the number of passengers, since air carriers intend to supply the demand. From the two Berlin airports, the most passengers are carried via Tegel. As can be noted from the figure, Schönefeld occasionally offers modest number of flights to München. However, in 2018 this is no longer the case. This means that for further analysis only the air traffic volume between Berlin and München via Tegel airport is considered.

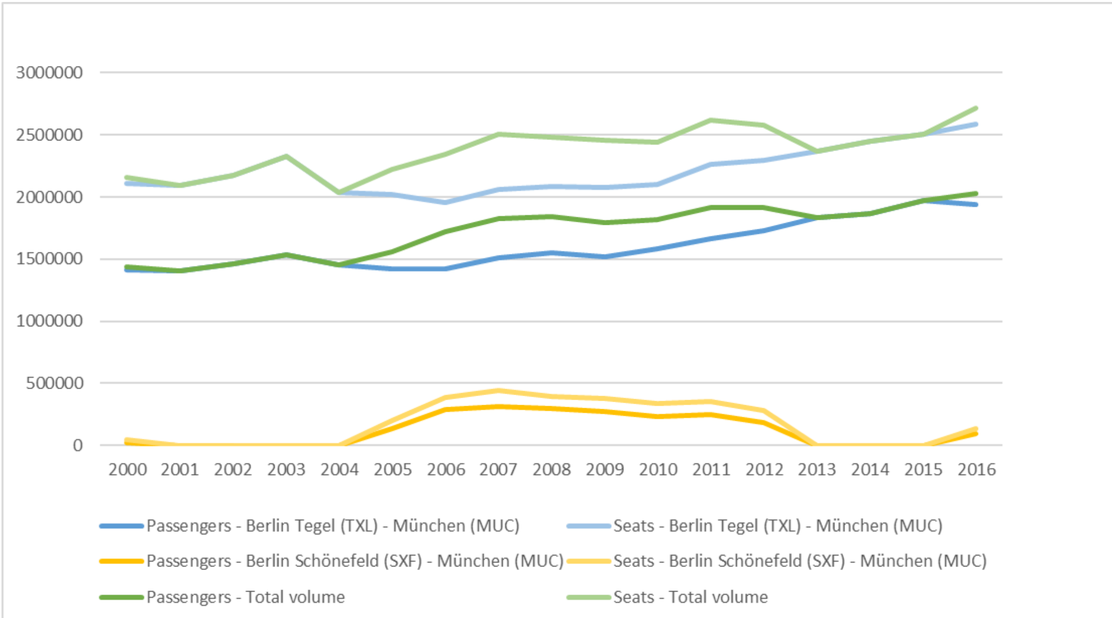

Figure 9 The development of passenger and seats of air travel between München and Berlin in the period from 2000 to 2016 (source: Eurostat, own elaboration).

Unfortunately, there is no public data available on the passenger traffic via HST between the two cities. One of the most important differentiating characteristics of the HST in comparison to the aircraft is that it operates within a network of intermediate stations. Therefore, measuring passengers travelling from solely from one station to another becomes more difficult. The HST figures are for this reason only analysed from a supply-perspective meaning that travel time, frequency and seat capacity in the current schedule are considered. This is elaborated in the next section.

4.1.2 Service levels

Table 2 compares the service levels of the HST and the aircraft service between Berlin and München in terms of average travel time, frequency and number of seats. Despite the introduction of the new high-speed rail track the average travel time is still in favour of the aircraft which by average is 56.4% faster. However, it should be noted that the ICE-sprinter service – which runs on average 8.3 times per day in both directions – enables a travel time of 240 minutes. In terms of daily frequency, the HST offers 55 route alternatives on average, which is 25% more than the aircraft. In these calculations are also routes included which require an interchange at an intermediate station, generally Nurnberg or Erfurt Hauptbahnhof. This is however only in 15% of the route alternatives the case.

Table 3 Long-distance mode comparison for week 24, 2018. Table includes data for both directions (source: passrider.com, bayern-fahrplan.de, own calculations)

Day	Date	Average travel time in min.		Frequency		Average number of seats per vehicle		Total volume of passenger seats	
		HST	Aircraft	HST	Aircraft	HST	Aircraft	HST	Airline

Mon.	6/11	290	132	56	50	405	170	22,680	8,520
Tue.	6/12	305	132	55	50	405	164	22,275	8,212
Wed	6/13	290	131	56	67	405	167	22,680	11,182
Thu.	6/14	291	135	55	23	405	166	22,275	3,810
Fri.	6/15	299	132	60	46	405	165	24,300	7,588
Sat.	6/16	314	130	51	42	405	173	20,655	7,260
Sun.	6/17	332	131	52	29	405	173	21,060	5,008
Day average		*303*	*132*	*55*	*44*	*405*	*168*	*22,275*	*7,369*

Flight data provided insight in the aircraft vehicle models operating per route alternative (refer to table 4). This made it possible to define the number of seats per vehicle and to calculate an average and the total volume of passenger seats weekly. Since for the HST connection were no figures available on the frequency per ICE-model the average seat number is used. The analysis shows that the capacity for the HST is with 22.275 seats (75.1% of the total for both travel modes) on average weekly considerably higher than for the aircraft, which only accounts for 24.9 %.

Table 4 HST and aircraft vehicle models carrying between Berlin and München based on their relevant characteristics (Lufthansa, Deutsch Bahn).

		Operating speed (km/h)	Seats
HST	ICE-3	300	420
	ICE-T	230	390
Aircraft	AIRBUS A319-100	840	138
	AIRBUS A320-200	840	168
	AIRBUS A321-100/200	840	200
	BOMBARDIER CR900	820	90

In conclusion, it can be stated that on the route studied the aircraft performs better than the HST in terms of travel time and is – given the fact that the HST sometimes requires an interchange – competitive about service frequency. The HST in turn performs better regarding seat capacity. A shortcoming of this analysis is however the absence weight factors to address the importance of each service level component.

4.2 Urban spatial structure of the Grossstadtregions

In this paragraph the urban spatial structure for the five variables is examined for both cases with the support of maps. The aim of this paragraph is to identify spatial patterns according to these variables within the case regions.

The population in both regions is clustered within the core urban zones (fig 10). However, the core area of Berlin covers a large surface and is situated quite isolated. The largest numbers of populations are situated in the Stadtbezirken of Mitte and Pankow. A comparable monocentric pattern can be observed for the München region. The largest numbers of populations are situated just around the city centre but still within the urban core. Nevertheless, it should be noted that both choropleth maps are case-relative representations where Berlin is obviously more voluminous than München.

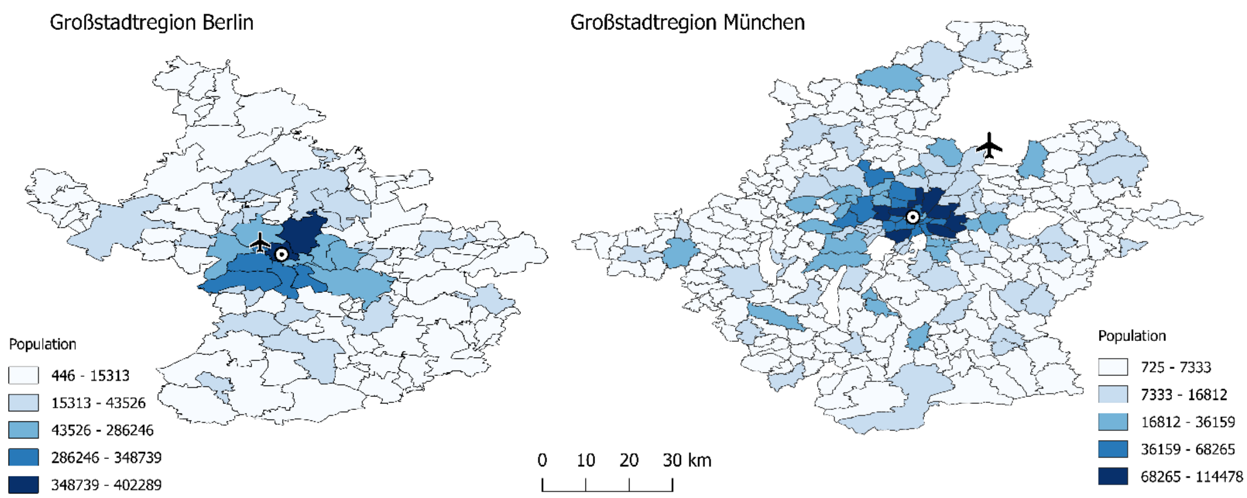

Figure 10 Spatial distribution of the population within the Großstadtregions of Berlin and München measured by inhabitants per spatial unit.

Comparing the absolute population distribution with its density (fig. 11) the same monocentric pattern can be recognised in which the core and complementary zones have the highest concentrations. In the case of Berlin, there is a vast contrast between the urban and the rural areas in the regional periphery. In Berlin, the Tegel Airport and the HST station are both situated in densely populated areas. Tegel is located in Reinickendorf – a Stadtbezirk within the core area of Berlin – and located just eight kilometres from Berlin Hauptbahnhof. Hauptbahnhof is situated Mitte, which is after Friedrichshain-Kreuzberg the most densely populated Stadtbezirk in Berlin. However, München shows a different pattern. Although the densely populated districts are clustered around München Hauptbahnhof, the airport situated 35 kilometres out of the city-core. The settlement pattern surrounding München is diverged into the eastern, western and to a lesser extent northern direction. The southern parts of the city border on wooded areas of which lower population densities are the result.

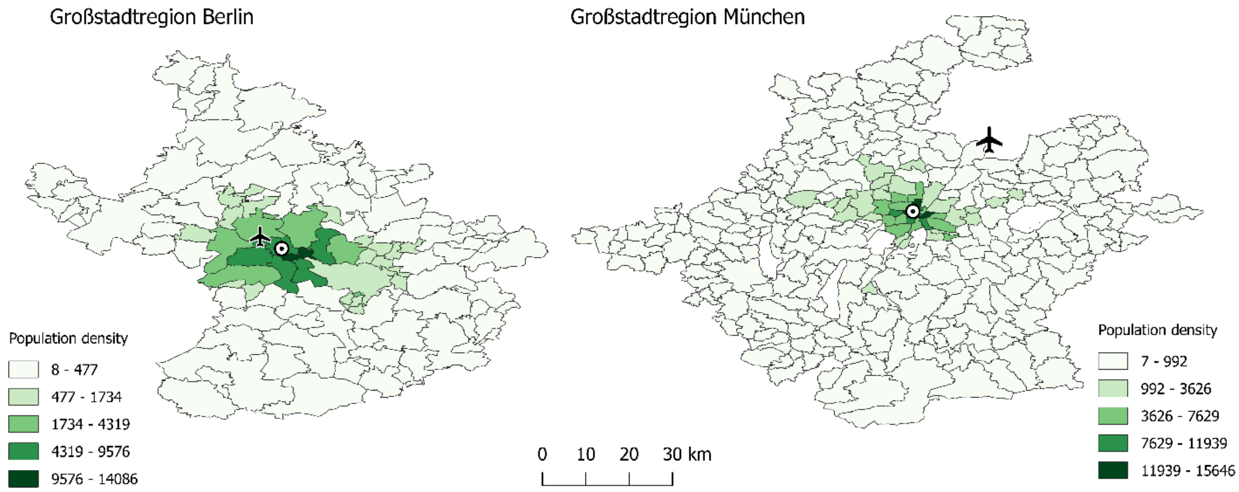

Figure 11 Spatial distribution of the population density within the Großstadtregions of Berlin and München measured by inhabitants per square kilometre.

The economy of Berlin is dominated by the service sector – which accounts for 85% of all employment – where there is a strong emphasis on education, research, culture and creative industries (OECD, n.d.). The map in figure 12 gives insight in the most important employment areas. Since Tegel and Berlin Hauptbahnhof are located at small distance from each other, both have good strategic positions in relation to the most essential employment areas. These areas are in the centre (Mitte), northwest (Pankow) and southwest (Tempelhof-Schöneberg, Charlottenburg-Wilmersdorf and Neukölln). The rural areas have low amounts employment, which are to some extent more concentrated in sub-regional centres around Berlin. However, also referring to table 5 this indicates that the regional employment structure is Berlin-centred.

The Großstadtregion of München is characterised by slightly different spatial employment structure than Berlin. Within the core are – which is the centre of gravity – the highest employment numbers are to be found in the concentric zones around the city-centre, of which Ramersdorf-Perlach and Neuhausen-Nymphenburg are the most important. From a regional perspective, the complementary employment area of München is substantially dispersed. Also, to some extent an axial pattern can be recognised between the city of München and the airport.

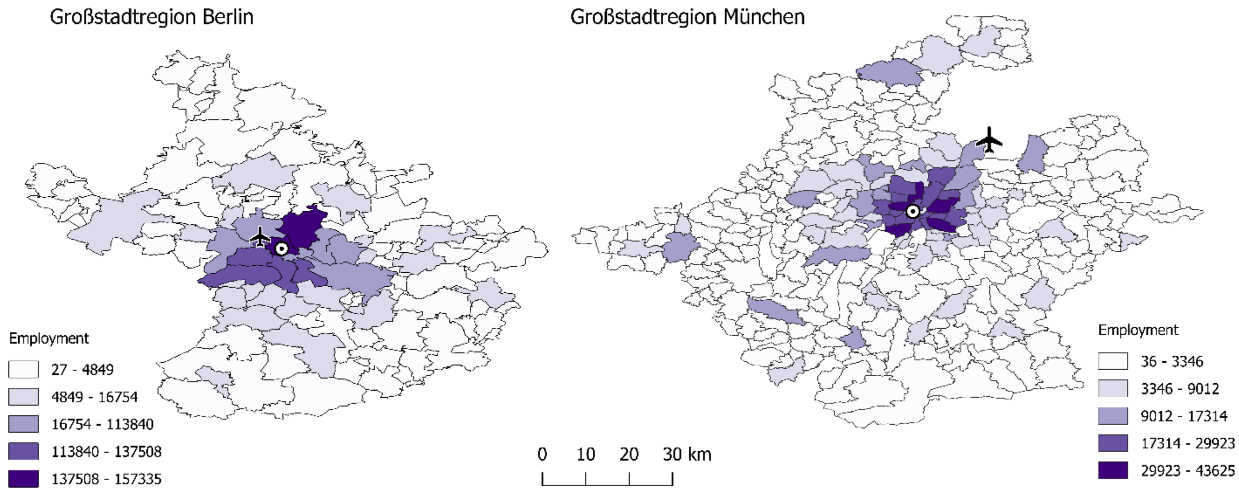

Figure 12 Spatial distribution of the employment within the Großstadtregions of Berlin and München measured by employees per spatial unit.

Distribution of income is depicted in figure 13. As argued in par 3.3.2, taxable income data were only retrieved on the municipal level. Therefore, the maps lack Stadtbezirk-specific income distribution. Nevertheless, the surrounding regions will be analysed. The direct surroundings of Berlin show higher income levels than the rest of the Großstadtregion, except the municipality of Bad Saarow located in the southeast. However, what stands out is that the taxable income in the Großstadtregion of München is much higher than in Berlin's. With the city of München as a pole of attraction, the municipalities with the highest averages of taxable income are situated in the south and southeast. Although not statistically tested, one could assume that for both regions, the areas located further away from the core urban zones have lower average taxable incomes. The similar trend can be understood from the results shown in table 5.

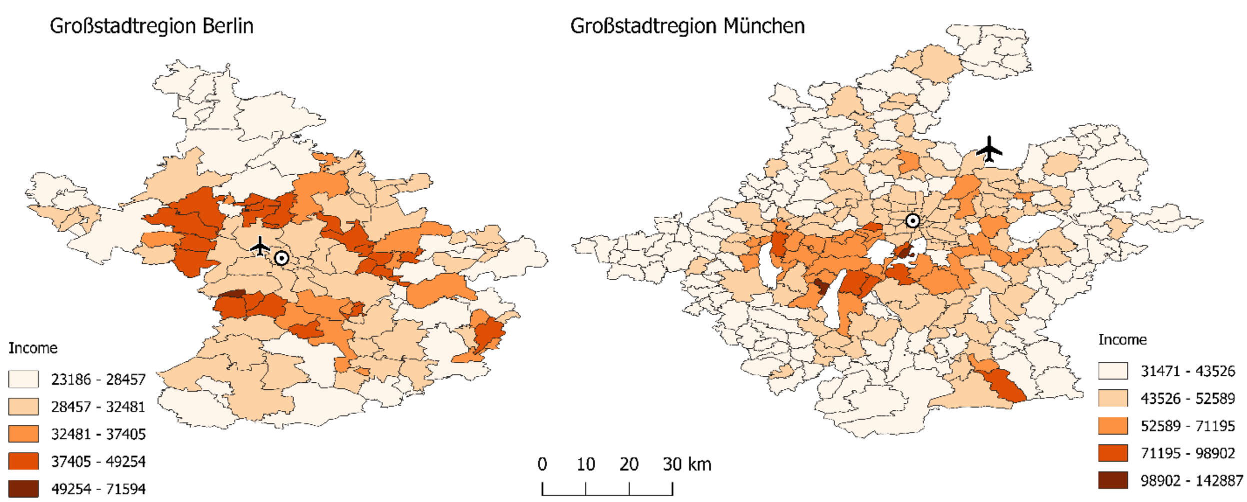

Figure 13 Spatial distribution of income within the Großstadtregions of Berlin and München measured by average taxable income per spatial unit.

Figure 14 elaborates on the spatial distribution of tourism destinations of which the total of overnight stays in 2016 is taken as a proxy. However, overnight stays do not only indicate tourism trips but business trips as well. Referring to table 5, the high standard deviations for tourism in both regions imply major differences between the spatial units. The city of Berlin attracts the most tourists of which Mitte is largest pole of attraction, followed by Charlottenburg-Wilmersdorf and Friedrichshain-Kreuzberg. Outside of the city Bad Saarow and Grünheide are the largest destinations. Tourism within the Großstadtregion of München more dispersed. The city itself attracts most of the tourists, both in the city and near the airport. Outside the city the areas located in the south show high values, which is most likely caused by alpine tourism.

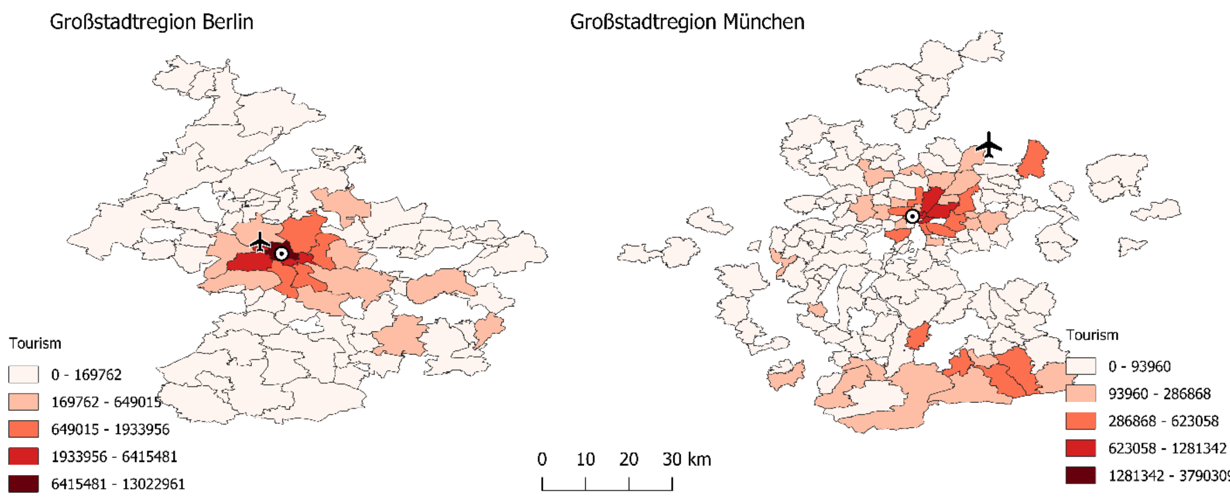

Figure 14 Spatial distribution of the tourism destinations within the Großstadtregions of Berlin and München measured by overnight stays per spatial unit in 2016.

In summary, the overall spatial patterns of München and Berlin show many similarities in their structure. Both core zones are the centre of gravity concerning almost all variables, resulting in a monocentric structure at the scale of the Großstadtregion. However, the major difference can be noted in the airport locations within each region. For München, the airport is located at a relatively large distance from the urban core. In contrast to Berlin, where the airport is located only several from the city centre. Concerning the urban spatial structure variables of population, population density, employment and to some extent tourism, this might implicate a larger relative competitive advantage for the airport in Berlin over München.

Table 5 Comparison of urban zones based on their urban spatial structure characteristics (own calculations)

Großstadtregion Berlin

Zone		Core area	Complementary area	Narrow commuter area	Wide commuter area	Total
Spatial units		12	19	30	48	109
Total surface		892	434	2283	4029	7637
% of surface		12%	6%	30%	53%	100%
Population	Total	3,711,930	300,216	444,453	229,965	4,686,564
	μ	309,328	15,801	14,815	4,791	
	σ	50,225	8,651	10,611	6,331	
Population density	μ	5,554	1,001	257	65	
	σ	3,506	619	205	85	
Employment	Total	1,460,530	88,921	130,689	68,670	1,748,810
	μ	121,711	4,680	4,356	1,431	
	σ	19,598	3,981	3,941	2,521	
Income	μ	31,433	39,941	34,502	28,818	
	σ	0	8,944	6,068	3,241	
Tourism	Total	31,067,775	983,835	1,658,331	1,376,123	35,086,064
	μ	2,588,981	98,384	78,968	52,928	
	σ	3,749,056	76,618	83,954	63,716	

Großstadtregion München

Zones		Core area	Complementary area	Narrow commuter area	Wide commuter area	Total
Spatial units		25	34	98	128	285
Total surface (km2)		311	591	2791	4679	8372
% of surface		4%	7%	33%	56%	100%
Population	Total	1,526,056	557,424	644,875	586,559	3,314,914
	μ	61,042	16,395	6,580	4,582	
	σ	22,010	9,134	6,416	4,860	
Population density	μ	7,234	1,215	248	141	
	σ	4,088	838	237	142	
Employment	Total	633,370	266,861	192,595	171,252	1,264,078
	μ	25,335	7,849	1,965	1,338	
	σ	8,361	4,998	2,845	2,236	
Income	μ	47,164	55,663	50,208	41,710	
	σ	0	19,509	13,803	7,095	
Tourism	Total	13,919,472	2,529,850	2,302,037	4,219,763	22,971,122
	μ	61,042	16,395	6,580	4,582	
	σ	784,981	77,050	52,683	87,565	

4.3 Terminal accessibility

4.3.1 Terminal accessibility by access modes

In this section the results of the analysis on the accessibility in terms of travel time to the HST stations and airports within both Großstadtregions by car and public transport will be discussed. When interpreting the accessibility maps[7], a potential bias arises as the accessibility calculations do not treat the regions as continuous areas but rather as a composition of discrete spatial units. Since the accessibility for both modes is measured from the centroids of these units, this means that average travel time decreases when the region is subdivided into more units. For example, the core zone of Berlin covering a total surface of 892 square kilometres is divided into 12 units, while the total surface of München is 311 square kilometres and divided into 25 units (referring to table 5). Therefore, when interpreting the results, one should be aware that the results of München have positive biases in comparison to Berlin since they offer a more precise representation.

As can be seen in table 5 the average access time to TXL by car is 44.3 minutes, which is 13% faster than the access time to Berlin Hauptbahnhof. Referring to the maps in appendix B1 and B2, the travel time to both transport terminals behaves in a more or less linear pattern since travel time increases with growing distance. However, the road transport axes diverging from the core zone result in better car accessibility for the spatial units around them. The same analysis in terms of public transport results in a favourable position of Berlin Hauptbahnhof, which is with an average access time of 59.7 min 26% faster accessible than TXL. For both transport terminals, the major difference between the median in comparison to the average indicates that the travel time by public transport is not equally distributed but has some extreme outliers in the upper range. When compared to the maps of public transport accessibility in appendix B1 and B2, the spatial pattern shows that the most densely populated areas in the core zone perform well, but the more remote areas in the north and southwest have poor accessibility. The overall picture for Berlin shows a favourable position for both the airport and the HST station. However, when leaving remote areas out of the analysis public transport is competitive to the car as the median scores demonstrate.

Table 6 Access times in minutes to the long-distance terminals by car and public transport.

	Berlin Tegel (TXL)		*Berlin Hauptbahnhof*		*München Franz Josef Strauß (MUC)*		*München Hauptbahnhof*	
	Car	*Transit*	*Car*	*Transit*	*Car*	*Transit*	*Car*	*Transit*
N	109	109	109	109	285	223	285	223
Min	8	24	11	11	8	7	6	6
Max	76	169	79	155	86	185	77	166
Median	47	75	51	52	42	90	41	50
μ	44.3	80.4	50.9	59.7	43.2	90.4	40.6	53.4
σ	15.5	30.3	15.4	29.2	16.1	30.9	13.1	28.2

[7] See appendix B.

The average access time to MUC airport by car is 43.2, which is only 6% slower than the access time to München Hauptbahnhof. Like Berlin, car accessibility decreases quite linear when distance increases. Especially visible for München Hauptbahnhof, diverging road transport axes from the core zone result in improved accessibility time for adjacent spatial units (see appendix B3 and B4). The same analysis in terms of accessibility time by public transport results in a favourable position of München Hauptbahnhof. The average access time of 53.4 is with 41% considerably shorter than for MUC airport. The central position of München Hauptbahnhof within the urban spatial structure combined with its nodal value is the most likely explanation for this difference. Appendix B3 and B4 show a diverging pattern of public transport axes from the core zone in which Hauptbahnhof is located. This is not the case for MUC airport due to its more remote location within the region. The overall picture of München shows a better car accessibility for both transport terminals, also when an outlier correction is considered when interpreting the median value.

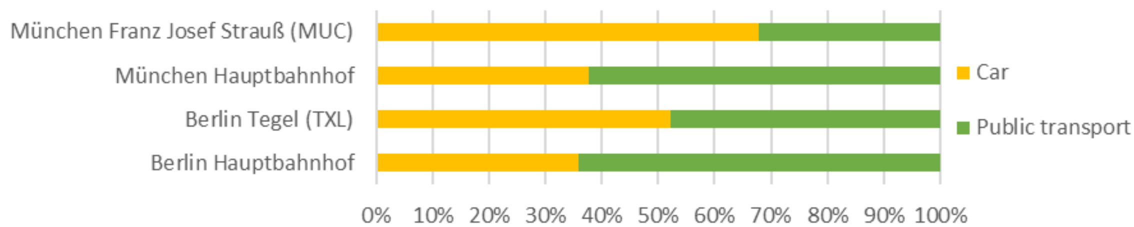

Figure 15 Modal split per spatial unit in terms of fastest access mode to transport terminals (%).

In summary, some claims can be made regarding the accessibility of the HST stations and the airports within both Großstadtregions. As argued by Martín et al. (2014), airports are better accessible by car, while HST stations perform better in terms of public transport accessibility. When the outliers are not included in the analysis, the analysis shows that this is only the case for Berlin Hauptbahnhof where public transport is competitive to the car when the outliers are not considered. However, one of the main differences between Berlin and München is the general accessibility of the airport to the HST station. For both Großstadtregions the HST is better accessible by both access modes of transportation, but for Berlin this difference is considerably smaller than in the case of München. The most plausible explanation for this difference is the position of both airports in their respective regional transport networks.

4.3.2 Access times per urban spatial structure variable

This subparagraph elaborates on the percentage of urban spatial structure variables that are accessible within a certain access time. As population density and income are indirectly measured variables they are not selected for the analysis because when the independent values are summed they do not reflect the total distribution of density or income within the urban regions. Nevertheless, population, employment and tourism provide insights in the sectoral attractiveness of HST or airports in terms of access time.

As visualised in figure 16, the accessibility of population and employment settlements is comparable in terms of their spatial distribution relative to MUC airport. Tourism shows a different pattern because its large settlement curve is followed by a smaller one for travel times between approximately 60 and 80 minutes. Referring to the map depicted in fig. 14, this is most likely caused by the high level of tourism destinations in the south of the Großstadtregion of München which is at the foot of the Alps mountain range. This area covers popular destinations for alpine tourism.

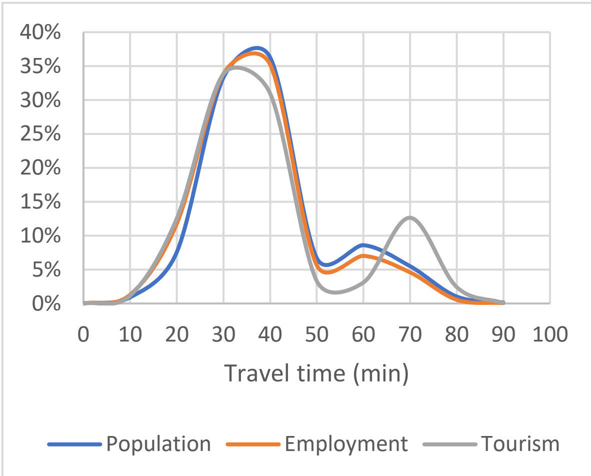

Figure 16 Percentage of population, employment and tourism settlements accessible within X travel time from MUC airport.

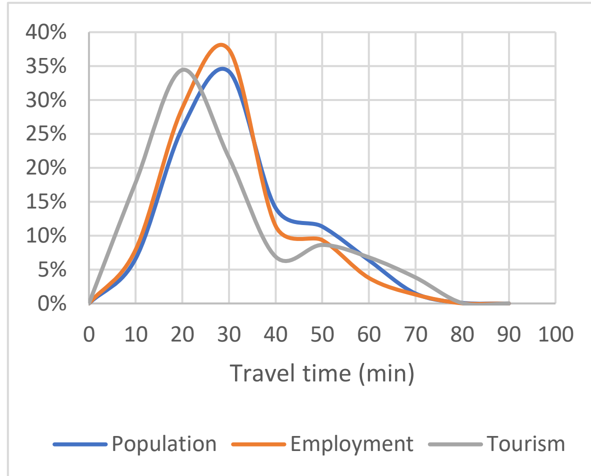

Figure 17 Percentage of population, employment and tourism settlements accessible within X travel time from München Hauptbahnhof.

When the travel times for MUC airport are compared to München Hauptbahnhof it becomes visible that both curves are visually comparable. Nevertheless, the largest percentages of all variables are shifted to the left which indicates that the HST station relatively speaking has a more central position than the airport. Especially tourism destinations have little travel times and are therefore likely to be situated near the HST station. In addition, the second curve for all the three variables is weaker for the HST. This might indicate that the HST station is more directly connected to these areas.

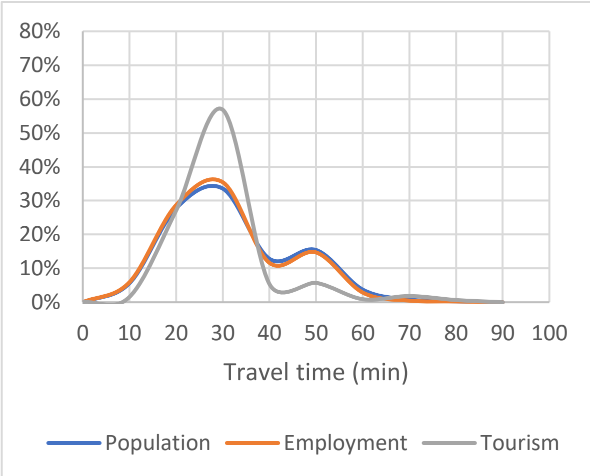

Figure 18 Percentage of population, employment and tourism settlements accessible within X travel time from BER airport.

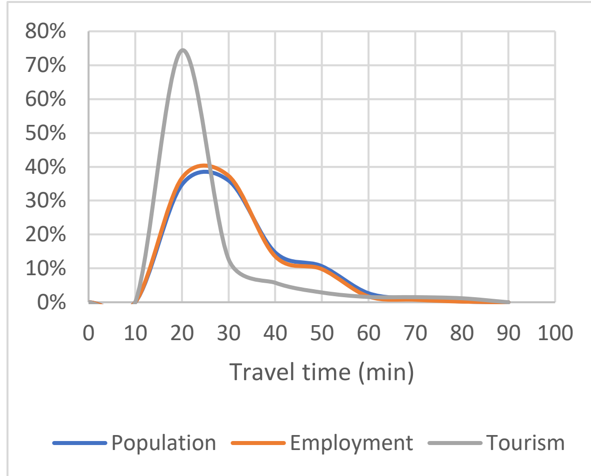

Figure 19 Percentage of population, employment and tourism settlements accessible within X travel time from Berlin Hauptbahnhof.

The Berlin counterparts show a quite similar pattern in terms of population and employment. However, the difference between the percentages served is less contrasting than was in the case of München. Its majorities are accessible between 10 to 40 minutes. As was already observed in the spatial analysis (par. 4.2), tourism destinations are highly concentrated within the core zone of Berlin. However, what is remarkable to see is that these areas are particularly concentrated at a travel time interval of 10-30 minutes from Berlin Hauptbahnhof.

In conclusion, the patterns observed for both cases have led to some assumptions. HST stations are better positioned regarding their accessibility towards settlements of population, employment and tourism, especially for München where the airport is located at a greater distance from the core zone than in the Berlin case. Furthermore, the accessibility distribution of tourism differs from population and employment. This might be caused by the two variables being more dependent to each other than tourism is. At least, this is the case on the level of the spatial units which were studied here.

4.3.3 Potential accessibility calculations

In this section, the potential accessibility for the HST stations and the airports is studied for both case regions. In the map depicted in fig. 20, two factors shaping modal competitiveness are combined: terminal accessibility and the service level of transportation modes. The service level of both transportation modes – a product of three components as elaborated in table 7 – is weighed by the shortest option in terms of travel time to each spatial unit. Thus, this can be either by car or public transport (for an indication of this split see also fig. 17 in 4.3.1). The result is a map that shows the relative advantage of both transportation modes from a spatial distribution perspective. The darker the colour, the larger the potential attraction of a transportation mode.

Table 7 Determination of the weight factors as a basis for analysing potential accessibility.

Service variables	Aircraft		HST	
	Absolute	Standardised	Absolute	Standardised
Seats (average per vehicle)	168	0.59	400	1.41
Frequency per day (both directions)	44	0.89	55	1.11
Average check-in time	40	-	-	-
Average check-out time	20	-	-	-
Average in vehicle-time	72	-	-	-
Travel time total	132	1.39	303	0.61
Weight factor		0.73		0.95

Referring to fig. 20, a complex interaction emerges between the two terminals in Berlin since the intermediate distance is only 8 kilometres. Therefore, the service level per transportation mode will have a larger impact on the potential accessibility in comparison to the travel time. The spatial pattern of the attraction of both modes per spatial unit is therefore interwoven to some extent. Nevertheless, the attraction of TXL airport is the strongest in the north-western part of the core zone (Reinickendorf and Charlottenburg-Wilmersdorf) and to lesser extent the hinterland in this direction. Berlin Hauptbahnhof performs best in the inner core of the city (Mitte and Friedrichshain-Kreuzberg) but is however less dominant in its hinterland in the south and west. For the Großstadtregion of München the divide between the attractiveness of the MUC airport and München Hauptbahnhof is clearer. MUC airport is very dominant in the regions in its direct environment and to a lesser extent in the more rural areas in the north and east of the region. München Hauptbahnhof has the highest attraction in the core zone and to a lesser extent in its southern and western hinterlands.

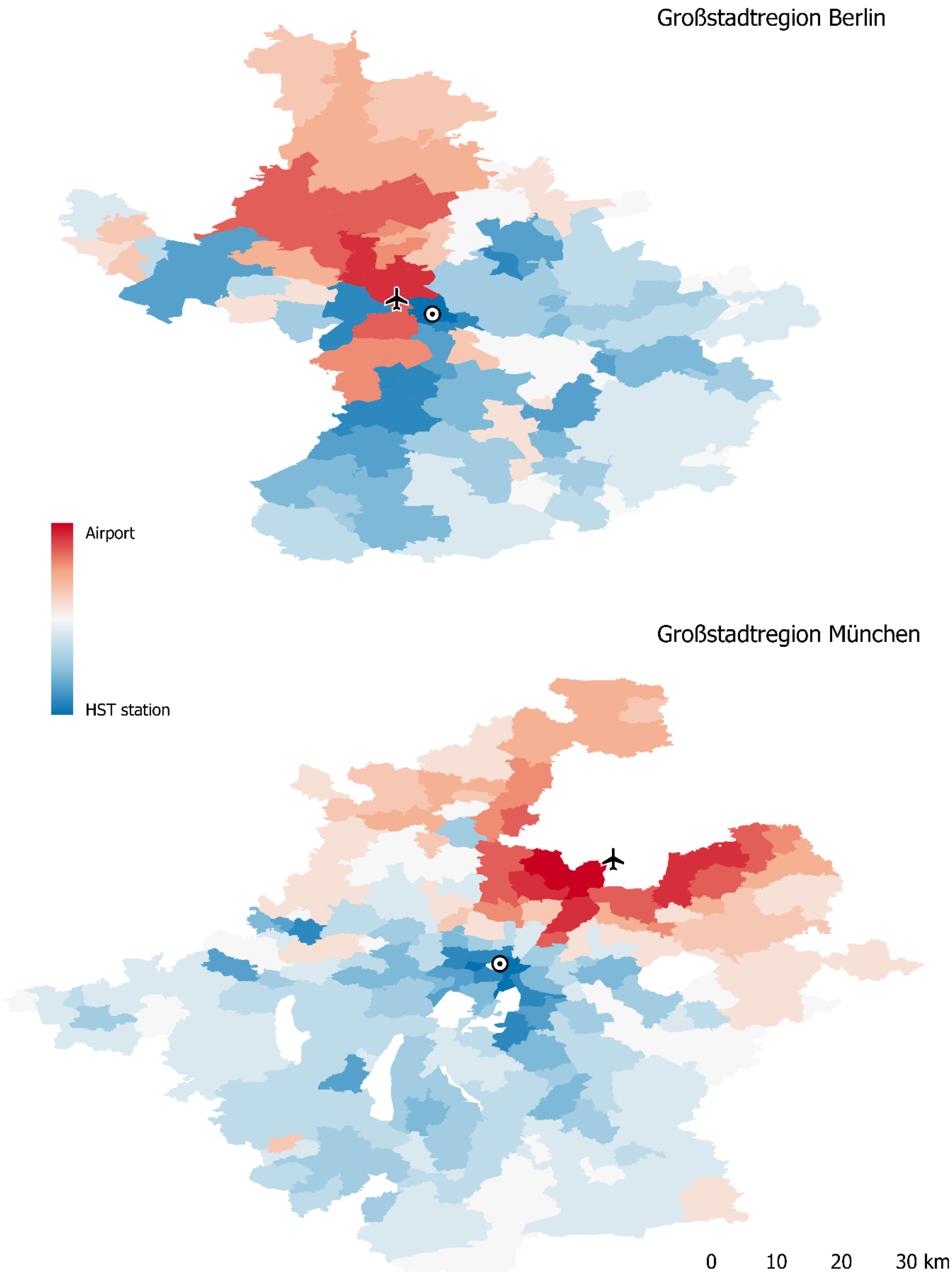

Figure 20 Potential accessibility according to service levels per terminal.

4.4 Conceptual discussion

The result section has elaborated on the service levels of the HST and the aircraft, the urban spatial structure of the Grossstadtregions of Berlin and München and the accessibility of the terminals. This paragraph aims at explaining the meaning and importance of the findings in relation to their conceptual context.

The concepts of the space of flows formed the basis for this research paper (Castells, 1996). From this starting point the concepts of interurban relations were discovered, in terms of the town- and city-ness of urban regions (Taylor et al., 2010). The assumption was made that HST and airline operations provided linkages between nodes within such urban systems. The Berlin-München route can considered to be such a relation but is however just a small part of the complex national urban system.

While the aim of this paper was to address the extent to which urban spatial structure influences intermodal competition, an answer to this research problem can therefore only partially be provided. Urban systems can be seen as the product of nodes and linkages in which the function of such spatial entities is scale-dependent (Burger & Meijers, 2012). Emphasis was on the spatial structure within the Großstadtregions of Berlin and München and its internal relational structure. Here, the structure in terms of the urban spatial structure variables was addressed. However, such an analysis was limited since only the relational aspects of passenger transport between the two cases were addressed. Therefore, no conclusions can be drawn in terms of urban spatial structure on the national level

When zooming in to this scale which was emphasised, the structural components were considered to be service level per transportation mode, urban spatial structure and terminal accessibility. Urban spatial structure is defined as the spatial expression of the market potential of a transport terminal, while transport terminals are the basis of the modes in long-distance transportation. The interplay between these components – or the connecting factor – is shaped by terminal accessibility. From a theoretical perspective, these components can be linked to the concepts of town-ness (Taylor et al., 2010). However, the methods applied in this attempted to bridge the gap between town-ness and city-ness by relating its characteristics to long-distance transport terminals. Town-ness is addressed by combining urban spatial structure and their relative distance to terminals and by the attractiveness of transport terminals in terms of service level and access time. This resulted in a description of how the functions of the case regions were spatially organised relative to access points in international networks. In conclusion, the results imply that the urban spatial structures of Berlin and München are characterised by monocentricity: the core areas of both case regions function are the point of centrality for population, employment and tourism and are characterised by higher levels of income and – in spatial terms – density of these functions. However, further research will be needed to offer a comprehensive overview which covers a zoomed-out perspective on the concept of urban systems.

5. Conclusion

The recent completion of the Verkehrsprojekt Deutsche Einheit nr. 8 has enabled the HST to travel between Berlin and München in under four hours. This development has revived the public debate on the possible substitutive role of the HST in relation to the aircraft on this route. Simultaneously, societal processes such urbanisation and globalisation are leading to new emerging spatial structures (Castells, 1996). Therefore, this paper aimed at providing an answer to the following central research question:

To what extent do spatial characteristics of urban regions influence the intermodal competition between high-speed trains (HST) and airlines for domestic long-distance passenger travel based on two cases in Germany?

Considering this central research question three central parameters were extracted from the literature and used to investigate the research problem: the service level of the long-distance transportation modes, urban spatial structure variables and terminal accessibility. The results are discussed throughout this last chapter and will be concluded by an answer to the research question. Subsequently, limitations of this study are addressed and recommendations for further research are proposed.

5.1 Discussion of results

The interaction between HST and airlines was studied by comparing their service levels for the Berlin-München route. The results show that the aircraft performs better in terms of total travel time, while the HST offers higher frequency services and greater seat capacity. The aircraft operates at higher speeds and even when check-in and check-out times are considered it remains the faster alternative. However, the results require further nuance from an economic perspective. As pointed out by Rodrigue et al. (2017), the interaction between the HST and aircraft consists of both competition and co-operation. EasyJet and Lufthansa – the air carriers currently operating on the route – have different objectives. The HST takes in a substitutive role in relation to low-cost airlines and a supplementary role to legacy carriers. While point-to-point strategies aim at linking two airports, the hub-and-spoke approach can benefit from a feeder system operated by the HST to supplement flight plans and free airport capacity (Givoni & Banister, 2007). The fact that MUC airport functions as a hub within the airline network of Lufthansa therefore offers co-operation opportunities for (partial) substitution of the aircraft on the Berlin-München route.

The urban spatial structure analysis provided insight in the functional structure of both cases. The results show that for all variables except income and to some extent tourism, the core urban zones are the centres of gravity within their urban region. This can be explained by the study of Zhong et al. (2014) which demonstrates that populous and dense urban centres are the optimal locations for HST stations. The results do however not provide a basis for conclusions on the conditions for the relative position of the airports to settlements within the urban spatial structure. The catchment areas of airports stretch beyond the geographical scale of the functional urban region (Chiambaretto, 2013). Therefore, the airports only partially depend on the catchment areas investigated in this study.

Access times to terminals are compared to population, employment and tourism distribution. The results indicate that the number of population and employment settlements for both cases are approximately equal on the scale of the spatial unit given their similar distribution relative to transportation terminals. Several authors argue that HST stations are better accessible in comparison to airports due to their proximity to urban functions in the core of urban areas (Givoni & Banister, 2007; Rodrigue et al., 2017). The results show for both case regions the same trend with lower access times to the HST terminals from population and employment settlement. Although speculative, the reason why tourism settlements concentrate at the urban core as well as more remote rural areas is due to differentiating trip purposes, such as city-trips and outdoor tourism.

The potential accessibility analysis combined HST and aircraft service levels with accessibility times to identify the attraction of the transportation terminals within the urban spatial structure. The results show that the competition between the modes in their overlapping catchments area is subject to the distance between them. In the case of Berlin, the airport and the central HST are located near each other and therefore their dominance of attractiveness is interwoven. In contradiction to München, where the in-between distance between the terminals is relatively large. This result partially underpins the argument of Givoni (2006), who states that areas with dense and dominant centres are more attractive to the HST. Regarding the results of this study this only applies to München, but not to Berlin. Furthermore, it should be noted that the results only account for potential attractiveness of the transport terminals. Statements regarding the influence of service levels on actual market shares as made by Dobruszkes (2011), can therefore not be justified due to this methods' limitations.

5.2 Answering the research question

In conclusion, the results discussed in the previous paragraph show that an answer to the research question is not straight-forward. The extent to which urban spatial structure influences intermodal competition cannot be directly measured with two separate data sets of urban spatial structure variables and transport supply figures. However, the research shows that terminal accessibility – besides the analysis on the accessibility itself – can be combined with both urban spatial structure and service levels of the HST and the aircraft. In the first case, access times per urban spatial structure variable provide insight in the percentage of each variable that is served within a certain time range. The results indicate that population, employment and tourism are concentrated in the core urban zones, of which the HST mainly profits. Second, the service levels weighed by their access times to the spatial units give an indication of the potential area of attraction. Although speculative, the analysis of this second analysis remains speculative. Therefore, the following hypotheses for further investigation can be proposed:

As distance between HST station and airport increases, the higher the level of attraction is acquired by an HST station or airport in its direct environment.

Otherwise, in the same line of argumentation:

Integrating an HST station at an airport will increase cooperation between the two modes and therefore the (partial) substitutive role of the HST.

5.3 Limitations and recommendations for further research

The scope of this study was limited to exploring to what extent urban spatial structure influences the competition between the HST and the aircraft. However, since the topic of this research has not been analysed thoroughly in academic literature in a qualitative setting, in-depth know-ledge on how the parameters of this study are related to actual travel behaviour is missing. Besides, the available data for this study did not approve to draw direct relations between the parameters. Therefore, it is recommended to adopt a more qualitative approach or mixed-methods approach to when a study on this subject is conducted.

During this research process, the speculative character of the subject difficulted the analysis. Therefore, I repeatedly strayed from the research strategy to explore how I could explain certain relations. In doing so, it became clear that investigating the socio-spatial context of long-distance travel may offer an extension to this research area. By identifying key competencies and interdependencies of actors and regulations involved in the long-distance travel market an institutional context can be drawn. This might explain how the different actors – such as railway companies, air carriers and federal government – interact and how contemporary long-distance travel markets are functioning. A widely used theoretical basis to structure the socio-spatial context is the Institutional Analysis and Development (IAD) framework by Polski and Ostrom (1999). Such a framework can assist research in comprehending complex social situations and to break them down into manageable sets of practical activities. Given the spatial scope of this research area, this might be rather useful.

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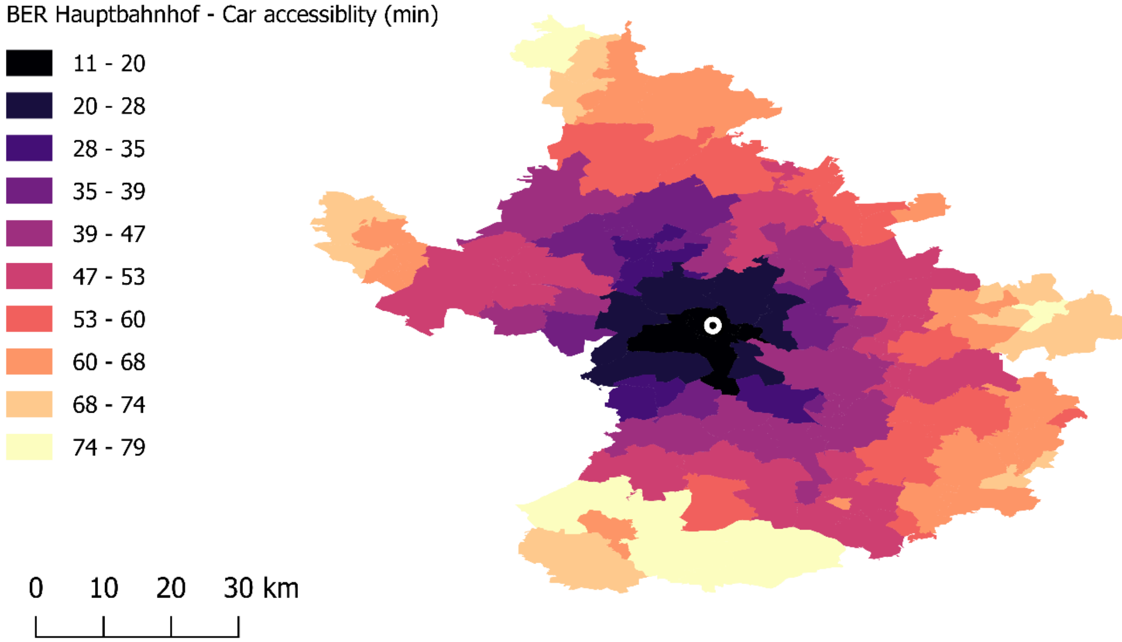
Appendix A – Systematic literature review

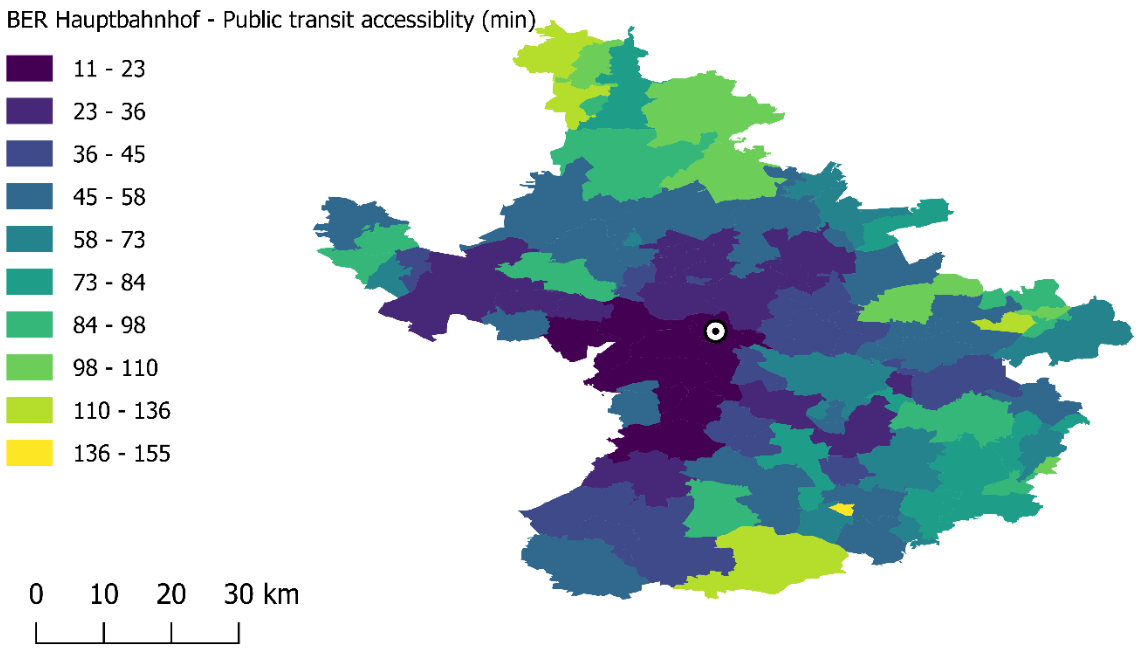
Author(s)	Aim of research	HST	Airline	Case regions	Spatial characteristics (variables)	Indicator	Data source
(Dobruszkes, 2011)	Comparing the overall dynamics in the supply of air transport in Europe compared to the HST supply and to examine empirically five city-pairs.	X	X	Metz/Nancy Brussels ls - London Marseille ie - München	Position of urban functions relative to transport terminals by different means of transportation: > City-centre > Business areas > Wealthy suburbs	> Public transport accessibility (travel time) > Car accessibility (travel time and distance)	
(Zhong et al., 2014)	Setting a context for policy discussion on HST feasibility from the perspective of station accessibility.	X		> Los Angeles - San Francisco > Madrid - Barcelona	> Population > Population density > Employment > Income	> Number of inhabitants (district/zip code area) > Population density (inhabitants/km2) > Number of employees (district/zip code area) > Normalised median household income (district/zip code area)	> US Census 2010 > Spanish National Statistics Institute (INE) > Catalan Statistics institute (IDESCAT)
(Martínez et al., 2016)	Focussing on the spatial influence of HST-stations, based on the notion of catchment area.	X		> Zaragoza > Valladolid Segovia > Toledo > Ciudad Real > Puertollano			
(Dobruszkes et al., 2011)	Examining the determinants of air traffic volume in the major European urban regions, with		X	> Functional Urban Areas (FUAs) in the liberalised	> Population > Gross domestic product	> Number of inhabitants > Million euros > Hierarchical administrative level (score)	> Municipal database (ESPON) > -

	paying attention to those that depend on the metropolitan features of cities			European air space	> Administrative function > Economic decision-power > Knowledge and scientific research > Tourism	> Several indicators > Several indicators > Number of beds/number of nights – tourist appreciation	> ESPON 1.4.3 > - > - > ULB-IGEAT--Michelin

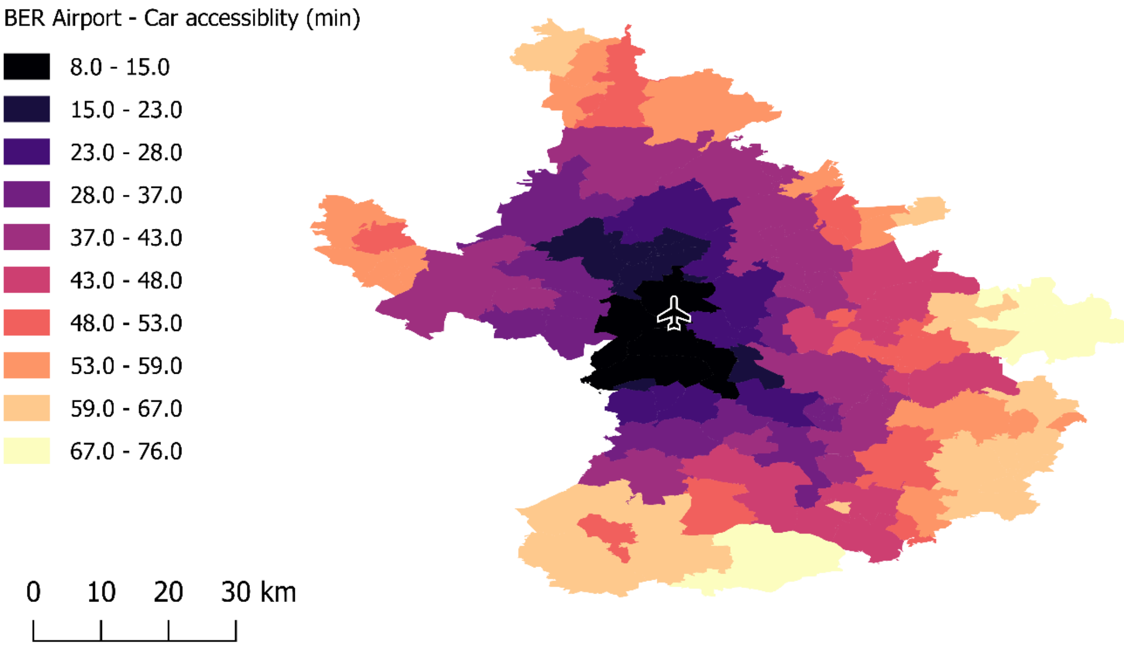
Appendix B – Terminal accessibility by access mode

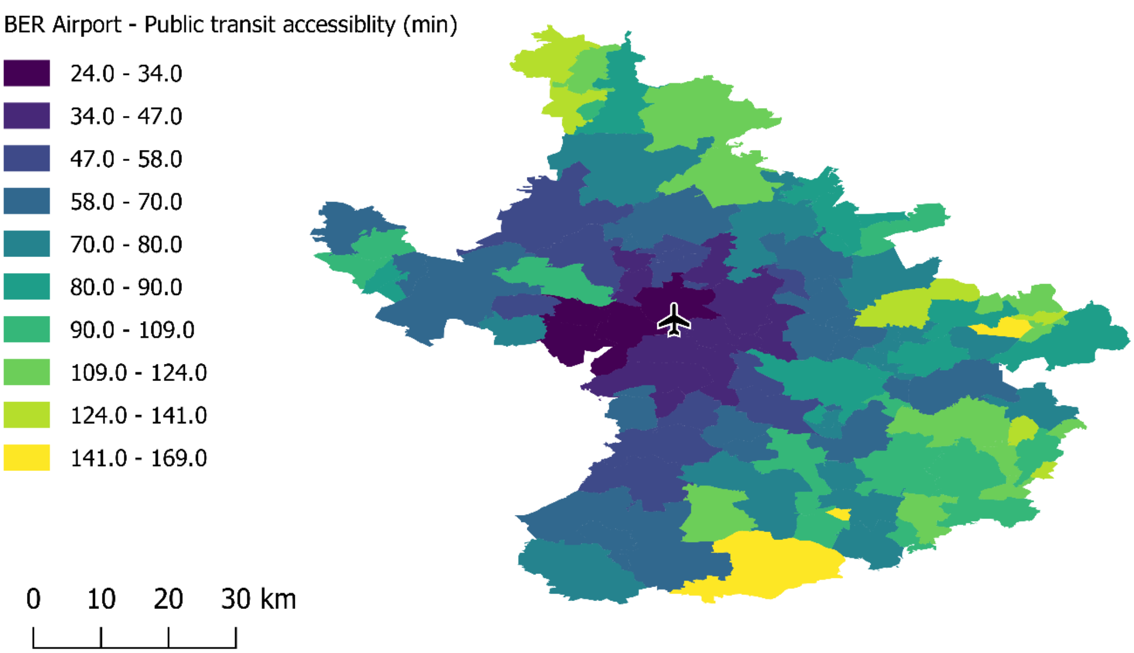
B1. Berlin Hauptbahnhof



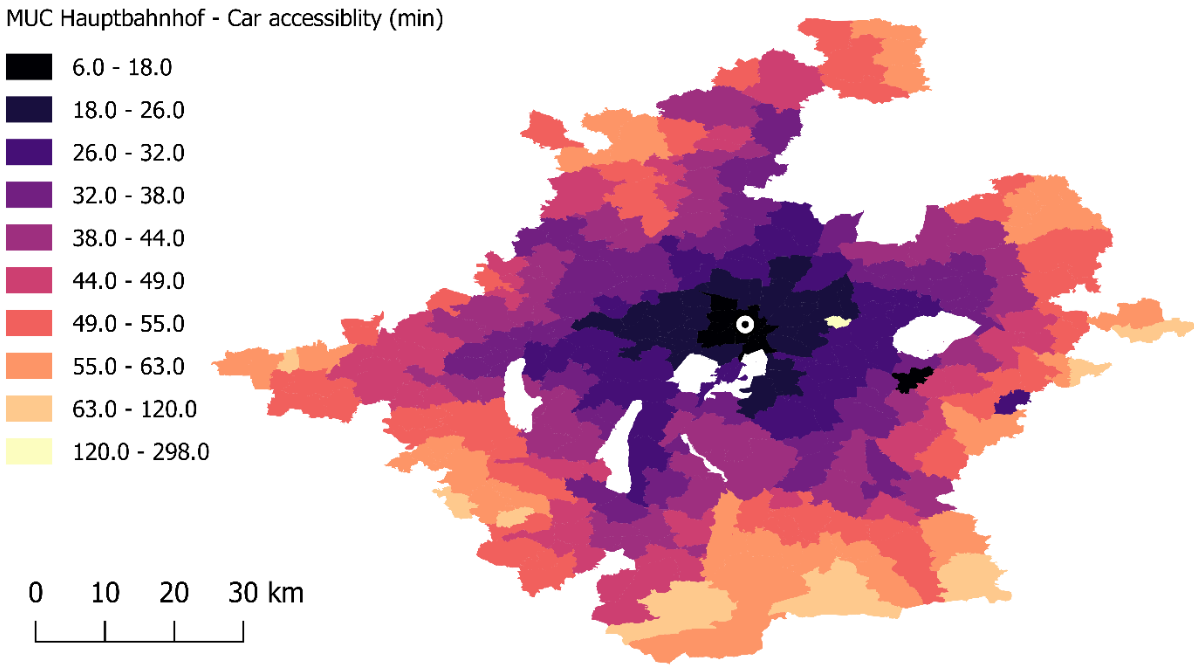


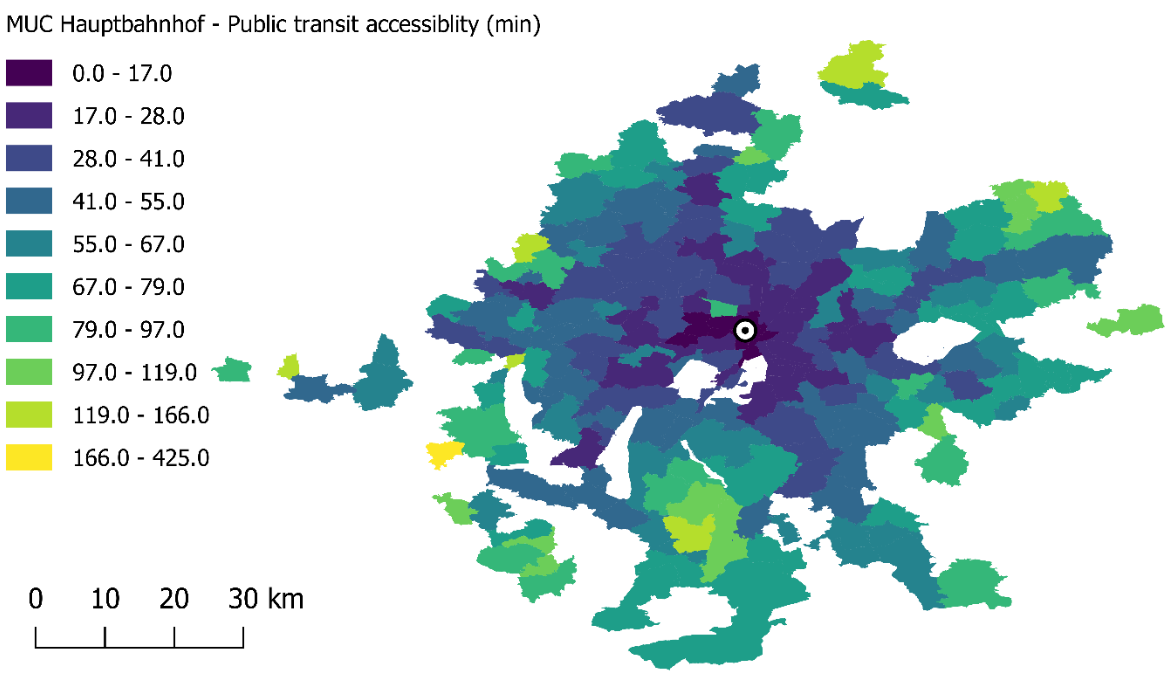
B2. Berlin Tegel Airport (TXL)



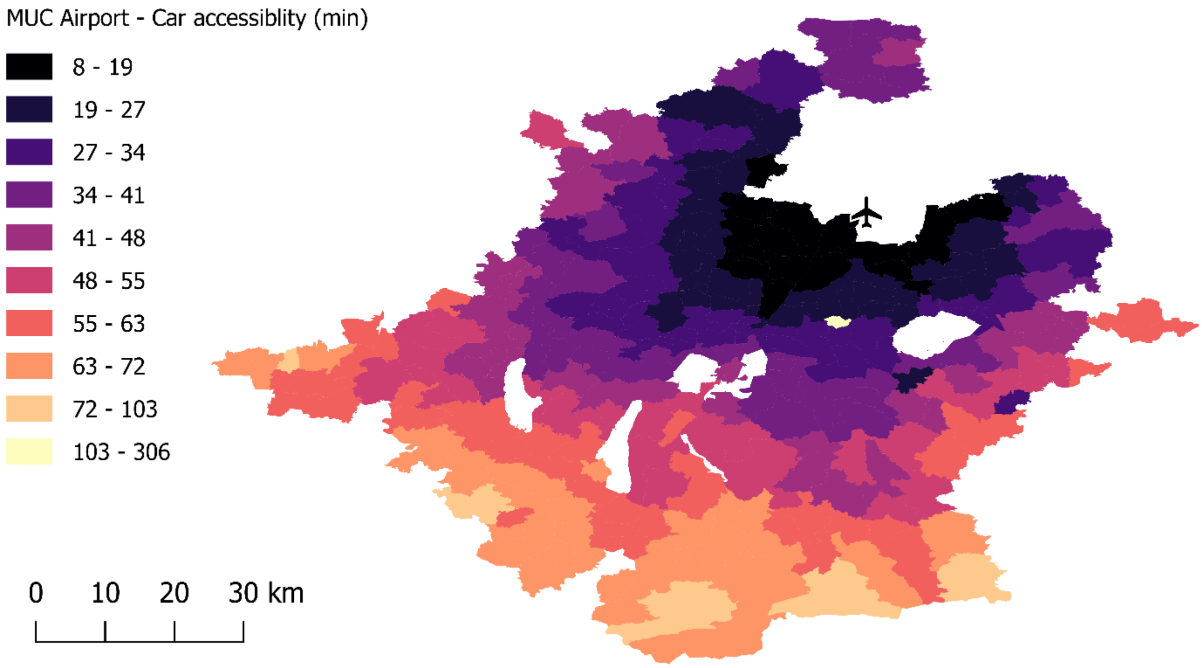


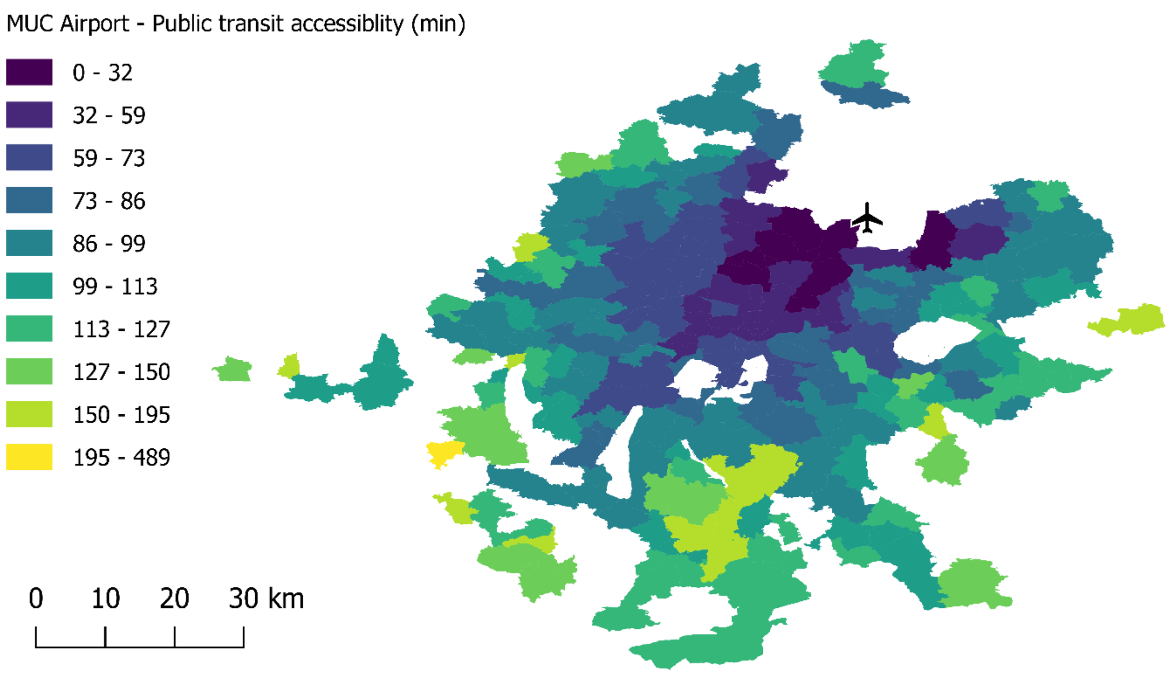
B3. München Hauptbahnhof





B4. München Franz Josef Strauß Airport (MUC)





Appendix C – Categorisation train stations Deutsche Bahn

Category	*Number of stations in Germany (2013)*	*Description*
1	21	Stations have a large and powerful infrastructure, have high travel frequencies and are technically stepless. In prestigious buildings, which are in the centre of the large cities, train passengers and visitors to the railway station will generally find all services related to the railway. The offer is complemented by numerous shopping opportunities, with great emphasis being placed on personal customer service. High-quality equipment materials ensure a pleasant ambience.
2	82	Stations are important access points for long-distance traffic or interfaces to the major airports and main stations of larger cities. All major infrastructural facilities and services around the train journey are available. In addition, a care of the passengers in rush hours by our staff is guaranteed. Equipment and service are at a similar level as at category 1 stations.
3	229	Category 3 stations are often main stations of small to medium-sized cities. The importance of traffic or the number of passengers at the 239 stations in this category is usually correspondingly large. The equipment is based on this: modern passenger information systems, elevators and escalators are to be found at such stations. Many of these stations have a reception building with various shops.
4	609	These include, for example, stations in metropolitan areas that are heavily influenced by regional and city traffic. Travellers are therefore often commuters with short stays at the station. The functional features are similar to those of a bus station and usually include weather protection and seating.
5	1012	This category includes stations of smaller towns and suburban stations, which are mostly used by commuters. These stations are less crowded, which is why they pay attention to a robust equipment that withstands vandalism. Less is often more here: instead of investing in unnecessary equipment, financial resources are used more effectively for cleaning and maintenance.
6	2501	Stations are usually located in sparsely populated areas in locations with small numbers of travellers and ensure the universal service in rail passenger transport. The equipment is usually limited to the essentials.
7	887	Stations in this category can be commonly referred to as 'land holdings'. The stations have a very simple or low infrastructure (e.g. only one edge of the platform). Due to their rural location they have very low traffic and therefore usually require neither the use of service personnel nor facilities of technical step clearance.