Intermodality – key to a more efficient urban transport system?

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Abstract
Cities are growing, ways of life and work are changing, people are increasingly mobile and interconnected – the urban population is constantly moving. Traffic congestion, emissions and increasing demand for parking space are among the consequences of these developments and confront society with new challenges. Especially in larger cities, flexible usage and combination of different transport modes – known as intermodality – plays an increasing role and is being discussed as a key to a more efficient urban transport system. Mainly in city centres, distances are short enough to be covered by foot or by bike and the close-meshed public transport network allows users to combine the variety of mobility options in an individual and situational way. A resulting declining use of private cars could reduce traffic congestion and emissions and challenge the lack of parking space in cities. Thereby, intermodality offers a possibility to optimize mobility and to contribute to healthier and more sustainable living in cities.

This paper presents mono- and intermodal travel modes' performance by means of accessible locations and sets them against the results of a survey on intermodality regarding the frequency of using various mono and intermodal travel modes. In addition, other performance indicators for the different modes are given, including the emitted amount of CO_2, personal energy consumption, and price.

Introduction: Intermodality – key to a more efficient urban transport system?
Growing cities and metropolitan regions in particular are faced with increasing traffic congestion, emissions and demand for parking space. As a result, private car use is becoming increasingly unattractive in cities. In contrast, new systems of bicycle rental and car sharing are evolving, services offered by public transport providers are increasingly integrated and the growing use of smartphones is simplifying access to traffic information and ticket purchasing (Knie 2013; Ahrens et al. 2014). Flexible usage and the combination of different transport modes – known as intermodality (Chlond 2013; Gebhardt et al. 2016) – plays a growing role in large cities (Heinrichs & Oostendorp 2015; Kuhnimhof et al. 2012) and is being discussed as a key to a more efficient – in terms of being friendlier to the environment, healthier, and more socially inclusive – urban transport system (Dacko & Spalteholz 2014). As a result of good public transport infrastructure and short distances in city centres, users increasingly combine walking, cycling and public transport in an individual and situational way (Heinrichs & Oostendorp 2015; Ifmo 2011; Cao et al. 2009).

The usage and combination of different modes of transport also offers the possibility to optimize mobility towards matching personal wishes in terms of costs, time, or activity (kcal) and to contribute to a healthier and more sustainable life in cities (less cars, congestions, emissions) (Kuhnimhof et al. 2012; Follmer & Scholz 2013; Dacko & Spalteholz 2014; Chlond 2013; Hall 2016). Combining different transport modes can help cut private vehicle use enabling cities to better cope with problems like traffic congestion, a lack of parking space and emissions.

In 1997, the EU Commission defined intermodality as an "essential component of the European Union's Common Transport Policy for sustainable mobility" (EC 1997: 24) and many public authorities promote intermodality as a key part of their urban mobility strategy (Hall 2016; Dacko & Spalteholz 2014; VDV 2013). However, it is vague as to the empirical basis for this claim. In addition, the benefits of intermodality for individuals, cities, and public transport operators have barely been investigated. Only few studies on the intermodal mobility behaviour of people in cities have been performed so far. Most of the studies referred to long distance traffic (e.g. Ubbels &Palmer 2013; Van der Hoeven et al. 2013) and only a few dealt with intermodality in everyday mobility (e.g.Dacko & Spalteholz 2014: 231; Köhler & Heinrichs 2014).

The German Aerospace Center (DLR) wants to close this knowledge gap. The Urban Mobility project (DLR 2015) analyses the systemic connections between the intermodal mobility behaviour of individual people, new mobility concepts and the built environment, using Berlin as an example. Berlin has a dense public transport network and good accessibility by foot and bicycle, favoured by the polycentric city structure and flat topography. Being a large city, new mobility services and trends emerge very quickly. In addition, private car ownership is low in comparison to other large cities in Germany (Senatsverwaltung für Stadtentwicklung und Umwelt Berlin 2014). Thus, a wide range of different mobility services provide good conditions in Berlin for combining different modes of transport to achieve flexible and situation-related everyday intermodal mobility (Jarass & Oostendorp 2017).

This paper attempts to provide concrete measures of the performance of combining different modes of transport. Due to the high relevance of trips to work or education for intermodal mobility behaviour on a daily basis (Jarass & Oostendorp 2017) the focus in the paper is on trips with this purpose. It uses the number of accessible work places over time, the amount of CO_2 emissions, personal energy consumption and price for this purpose. These indicators were chosen due to being proxies for the performance of the regarded mobility types in terms of travel time, ecological footprint, users' health, and social inclusion.

In this paper the following research questions will be analysed:

- Which modes of transport do people in Berlin use and combine when they travel to work?
- What are the differences between monomodal and intermodal trips with regard to accessibilities, emissions, personal energy consumption, and price?
- What is the interdependency between intermodal mobility and the characteristics of urban spaces and infrastructures?

The paper starts with a definition of intermodality. Next, the results of the user survey performed within the project are given, focussing on intermodal mode shares for trips to work. Then, differences in amounts of work places accessible by different modes and intermodal mode combinations are investigated. The monomodal modes walking, bicycling, and driving a private car are considered as well as their respective intermodal combination with public transport. This is followed by a presentation of other indicators – pollutants emission, personal energy consumption, and price. Finally, dependencies between the mode shares and the computed accessibilities are discussed.

Intermodality – definition and characteristics

INTERMODALITY – A QUESTION OF DEFINITION

Many prevalent definitions, according to which intermodality is defined as a combination of different modes of transportation in the course of a single trip (Chlond & Manz 2000), admit far-reaching interpretations. Therefore, knowing how many journeys in everyday life are considered as 'intermodal' depends on the exact definition of intermodality. Basically, intermodality is a subset of multimodality (Nobis 2007). Multimodal travel behaviour refers to the use of different modes of transport within a fixed period of time (e.g. one week), e.g. one trip by bike, one by car, and the next by foot (Ahrens et. al 2014). In contrast, intermodal travel behaviour is understood as "the shipment of cargo and the movement of people involving more than one mode of transportation during a single, seamless journey" (Jones et al. 2000: 349). Therefore, a distinctive feature of intermodality is the interchange from one mode of transportation to another one (Beutler 2004; von der Ruhren & Beckmann 2005), whereas this is not relevant for multimodality (Jarass & Oostendorp 2017).

With regard to public transport, several interpretations exist whether the combination of different means of public transport should be regarded as an intermodal trip. In this paper, the consecutive combination of at least two public modes of transportation (e.g. bus and metro) is considered as an intermodal journey (Yeh 2008; Olvera et al. 2014; Gebhardt et al. 2015).

It is debatable how walking can be interpreted in the context of an intermodal trip and, especially, if it can be assumed as an "independent mode of transport" (Last & Manz 2002). The use of public transportation is connected necessarily with walking because "almost all origins and destinations are more than 25 metres away from the next public transport station" (Thomas & Schweizer 2003). Other studies regard walking as one part of an intermodal trip if the walking duration amounts to at least five minutes (Diaz Olvera et al. 2014). However, walking distances can be assessed very differently by different user groups. That makes it difficult to gather this information empirically. In the empirical results described below, the combination of walking with another mode of transport is not treated as intermodal behaviour. Nevertheless, intermodal trips can also include stages by foot.

INTERMODALITY IN THE CITY – EMPIRICAL RESULTS WITH FOCUS ON TRIPS TO WORK

Existing German mobility data sets, such as SrV (Mobility in Cities – System of Representative Transport Surveys) or MiD (Mobility in Germany), and other research studies only provide limited information on intermodality and hardly any spatially differentiated analyses. In order to expand the empirical basis of intermodality and to examine the topic from a wider perspective, an empirical survey was conducted in Berlin in spring of 2016 within the framework of the "Urban Mobility" research project.

The analysis of the cohesion of intermodal mobility behaviour and spatial structures is a central aspect of the study. Therefore the survey was conducted in spatially different areas in Berlin. For the identification of these spatially different categories, all planning areas in Berlin were clustered using attributes that describe mobility (access to public transport services and mobility resources of inhabitants) and urban fabric (population, building and supply density), which were defined through an analysis of spatial data. The territorial units in the empirical studies were nine so-called planning areas (PLR), belonging to three different spatial categories: (1) decentralized neighbourhoods, (2) urban neighbourhoods and (3) well-connected neighbourhoods (see Figure 1). The decentralized neighbourhoods are especially characterized by a high car orientation and predominantly outer location. The urban neighbourhoods have very good infrastructure provision on-site and thereby low distances while the well-connected neighbourhoods show extremely high connectivity with public transport. Taking into account high consistency with the respective cluster characteristics and after performing a qualitative on-site check on suitability for the survey, three planning areas per spatial category were selected as study areas. Figure 1 shows the three spatial categories and the nine selected study areas in Berlin at PLR level.

For each planning area, a representative sample concerning age (14 years and older) and gender was selected from the Berlin register of persons. Respondents were invited by letter to complete an online questionnaire. The survey was carried out from mid-February to mid-March 2016 and obtained 1,098 responses. Response rates were relatively balanced between the three spatial categories.

The results from the survey showed that intermodal mobility behaviour is more widespread than revealed by initial evaluations of existing surveys with a reference date. Of the 1,098 respondents, 83,5 % stated they combine different modes of transport. Only 16,5 % of the people asked said that they never combine different modes of transport on a single trip. The high number can be explained by the fact that every combination, regardless of frequency, was of interest, unlike in surveys with reference dates (Gebhardt et al. 2016; Jarass & Oostendorp 2017). This therefore provides a broader overview of intermodal mobility behaviour, and, also, occasional intermodal behaviour.

Existing secondary data analyses (Gebhardt et al. 2016; Jarass & Oostendorp 2017) as well as the results of this empirical study show that intermodal combinations are more often used on trips to work or education and for leisure activities than for other trip purposes (see Table 1). Nearly one third (30,8 %) of respondents stated that they combine different modes of transport on their trips to work or education on a daily basis whereas intermodal travel behaviour for other purposes is less common.

Due to the high relevance of trips to work or education for intermodal mobility behaviour on a daily basis, the focus in the presentation of the empirical data as well as in the calculations presented later on, is on trips with this purpose. About three-quarters of respondents were working or in education. However, percentages in analyses refer to all respondents to get an impression of the relevance of intermodality for the whole city population.

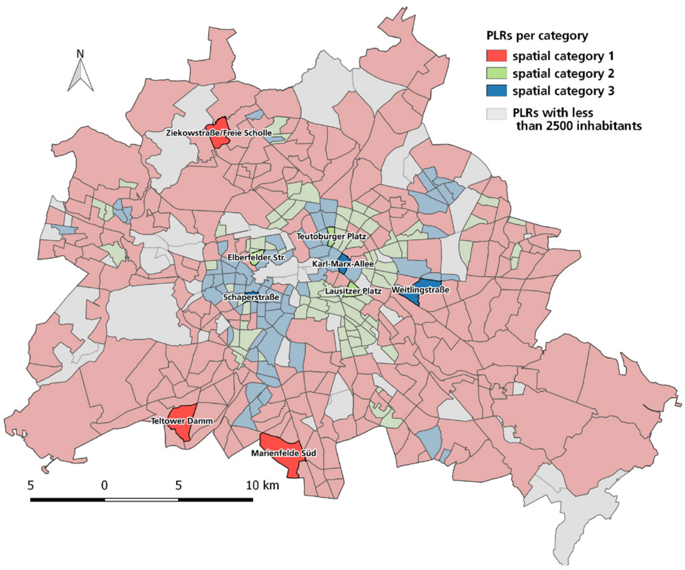

Figure 1. Spatial categorization of Berlin's PLRs; areas of survey highlighted.

Figure 2 shows the percentage of people using or combining certain modes of transport on a daily basis and less frequently on trips to work or education. The share of daily use emphasizes the relevance of intermodal travel behaviour in everyday mobility. The empirical results show that almost a quarter of respondents use intermodal transport by combining several public transport modes on a daily basis; 12,5 % of respondents report using only one mode of public transport. It is also common for Berliners to use the bicycle on the way to work or education (18,1 %) or to combine bike and public transport (7,9 %). Daily use of a private car on trips to work is quite low at 12,8 %. Due to the aforementioned reasons and because walking to a station does not correspond to changing between car, bicycle or public transport, walking was not asked for within the survey.

The chosen research approach allows us to draw conclusions about the relationship between people's mobility behaviour and their place of residence. Intermodal behaviour on routes

Table 1. Share of persons doing intermodal trips with a certain frequency, differentiated by trip purposes.

Trip purposes	Daily intermodal	Less than daily intermodal	Never intermodal
Work/education	30,8 %	27,4 %	41,7 %
Recreational	16,2 %	64,8 %	19,0 %
Work related	8,2 %	64,6 %	28,2 %
Shopping	7,5 %	56,6 %	35,9 %
Personal business	7,3 %	39,4 %	52,5 %
Pick up and bring people	3,7 %	46,7 %	49,6 %
Transport of goods and material	2,6 %	44,4 %	53,0 %

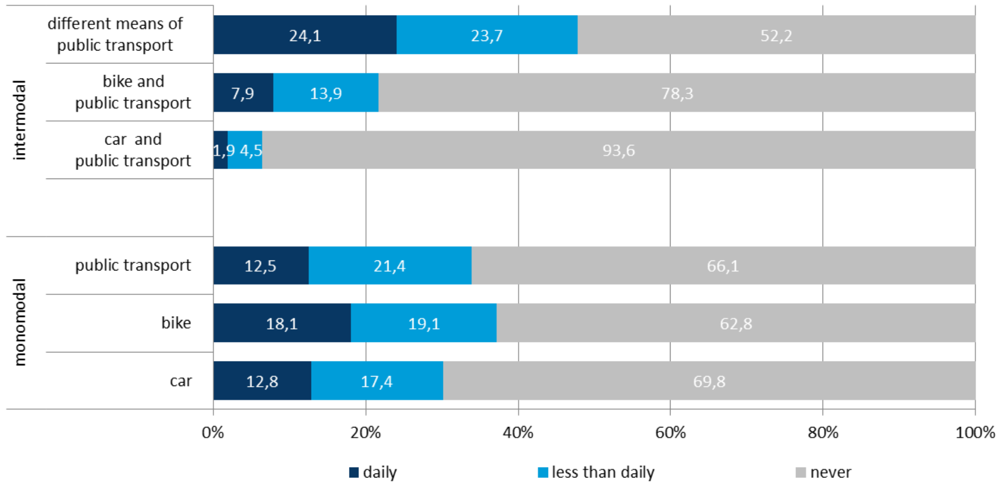

Figure 2. Frequency of intermodal and monomodal use of means of transport on the way to work or education (n = 1,098 persons).

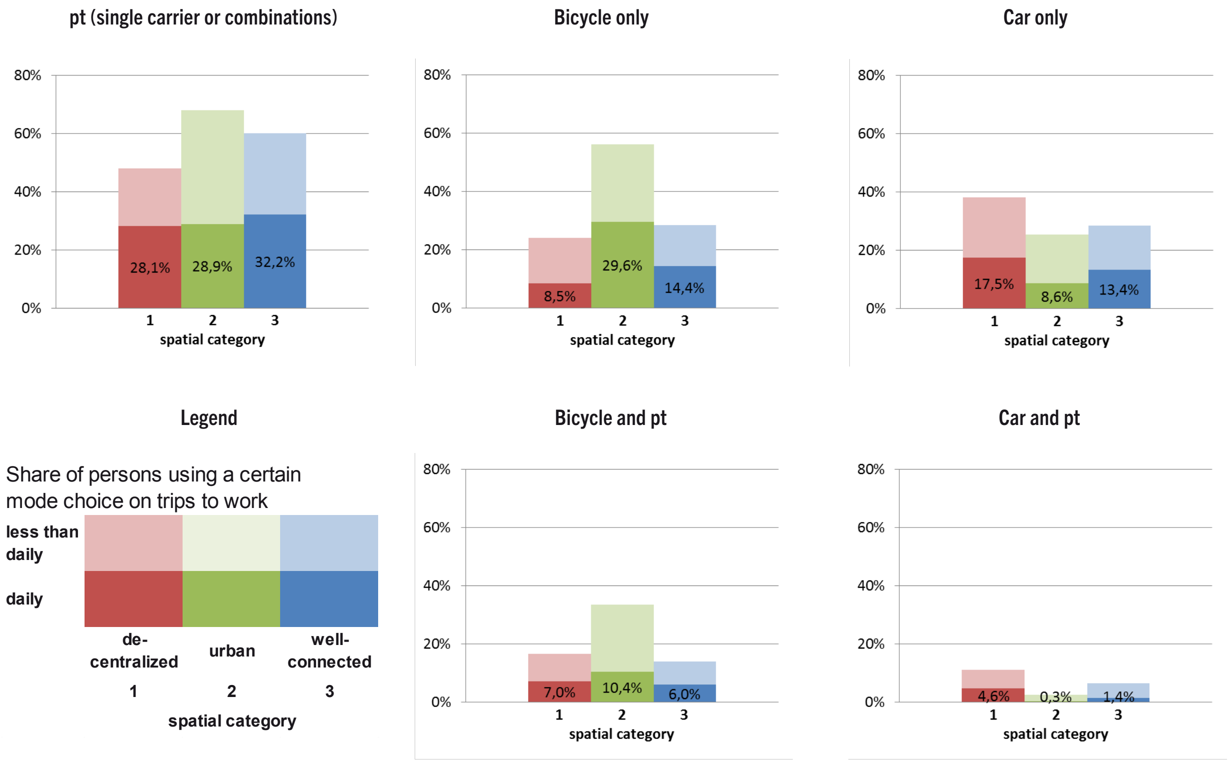

Figure 3. Shares of mode and mode combinations on trips to work.

to work is to be found in approximately equal parts in all three spatial categories: 31,3 % of people living in decentralized neighbourhoods use intermodal mode combinations to work on a daily basis, 30,9 % in urban neighbourhoods and 30,4 % in well-connected neighbourhoods. Transport use on the way between home and office is shown in Figure 3 for both monomodal and intermodal use. Clearly, the shares differ between the spatial categories. For example, monomodal car use represents the most important mode of transport for people living in the decentralized neighbourhoods (spatial category 1). The situation is different in the urban neighbourhoods where the bicycle is the most frequently used mode. This supports the assumption that distances to work are, on average, relatively short in these neighbourhoods. This will be investigated in later sections. Public transport is widely used in all areas but, by comparison, the well-connected areas (spatial category 3) show the highest share.

The spatial differences in shares of using intermodal mode combinations are similar to the ones found for monomodal trips. The combination of cars and public transport in the decentralized neighbourhoods (spatial category 1) is significantly higher than in the other areas. A park & ride scenario could be an option for people living in these areas to avoid using a car in the city centre. In the centre, the car is less attractive because of a lack of parking space and traffic congestion. At the same time, car use seems to serve as a feeder to public transport in areas where accessibility to public transport is poor. Bicycle and public transport are used by significantly more people in the urban neighbourhoods (spatial category 2) than in other areas. By looking at the use of public transport, it is clear that the type of transport used is influenced by residential location, and that the number of transport modes used on a trip is also linked to spatial factors. The percentage of monomodal public transport routes in the more central areas (spatial category 2) and well-connected (spatial category 3) neighbourhoods is higher than in the decentralized areas (spatial category 1) (see Figure 1), while in the case of intermodal public transport routes, the frequency of daily use is approximately the same in all three areas. The differences in monomodal public transport trips can be explained by, among other things, the (on-average lower) distance and journey-time of routes in inner city areas in Berlin (Jarass & Oostendorp 2017).

To sum up, empirical results show that daily intermodal mobility behaviour is particularly relevant on trips to work. The use of combinations of bike and public transport as well as car and public transport on trips to work show spatial differences between places of residence reflecting the monomodal use of bike and car, respectively.

Mono vs. intermodal trips

Attempting to reveal the interdependency between the performance of different modes and mode combinations and these modes' usages as reported, intermodal mode combinations were first compared against monomodal travelling in terms of travel times. These comparisons are based on the concept of "accessibilities" (Litman 2003).

In the following, disaggregated values from computing so-called "contour accessibility measures" (Scheurer & Curtis 2007) are used, meaning the number of destinations accessible from a set of origins within a given time limit. The analyses focus on daily trips from home to work, because they are assumed to be the most stable ones in terms of choosing a specific mode of transport due to their daily routine and the users' wish to optimize them. Home locations are used as origins and work places as destinations. Neither the users' attitudes towards the transport modes or their combinations nor any kinds of decay functions are used. Consequently, using pure contour accessibility measures neither takes the users' preferences for using certain transport modes into account nor their personal capabilities to perform the trips. It is a purely artificial attempt to describe the theoretical performance of intermodality. Nonetheless, the authors assume that such an approach allows measuring the performance of intermodality in a clear, concrete way, without diffusing it with additional – theoretical – variables. It is thereby valuable for describing an area's mobility characteristics rather than the respective users' behaviours.

The computation itself was performed using the software tool "UrMo AC" (Krajzewicz & Heinrichs 2016) which computes contour accessibility measures. The tool reads the locations of origins and destinations, the road networks, as well as a representation of the public transport offer from a database. Different limits can be set, including a maximum travel time, distance, number of destinations to visit, and others. The computation itself is performed using a plain Dijkstra algorithm, starting either at every, or at a sub-set of the loaded origins and stopping after reaching the defined limit. While computing the accessibilities at the level of single buildings, the tool allows defining variable aggregation areas within which the computed accessibilities are averaged. For its application within the Urban Mobility project, the tool has been extended by the capability to compute intermodal accessibilities. The extension includes changing mode during a trip, either leaving the initially used carrier at the interchange or taking it on board of the subsequently used carrier. Accordingly, possibilities to define limitations of carrying a certain vehicle (e.g. a bike) within other modes (e.g. city rail) were added.

For comparing the accessibility measures against the results of the survey, the region regarded within the accessibility computations shown in the following covers the area of the city of Berlin. The data used includes the definition of the public transport services for the year 2015 given in the GTFS format and a digital road network representation from NavTeq from the second quarter of 2012. Travel times for motorized individual traffic were computed using the microscopic traffic flow simulation SUMO (Krajzewicz et al. 2012) using an adapted version of the same road network representation and a demand computed for an average day using the agent-based demand model TAPAS (Heinrichs et al. 2016). The information about dwellings in Berlin used as input for the origins was supplied by the administration of Berlin and describes June 2012. Overall, this dataset describes the positions and ground plots of 546,672 main and side buildings. The data set of points of sale from NEXIGA was used to model the destination work places. It consists of 168,507 business locations and replicates the year 2012 as well. All computed journeys start at 8:00 am, matching the morning peak hour.

Within the following computations of intermodal accessibilities, taking a bicycle on board of a metro train, a city rail, a ferry, and trains operating within Berlin is allowed. Buses and trams were removed from the public transport definition when computing intermodal usage of bicycles and public transport, because it is not allowed or, respectively, uncommon to take bicycles on board. This matches the regulations given in Berlin. Of course, a passenger car has to be left at the first public transport station. In this case, after leaving public transport, the remaining time is spent walking.

Table 2 shows the values of the parameter that were chosen for the evaluations shown in this and the following sections. One may note that neither delays at interchanges, nor access/regress, nor parking times to individual transport modes besides access to public transport stations are modelled.

These constants are relatively coarse; walking and cycling speeds may be higher, especially when regarding trips to the workplace, which are usually performed in a time-optimal way. In addition, using the scheduled travel times of public transport ignores possible delays due to being stuck in heavy traffic when dealing with buses and trams, which use the same infrastructure as motorised public traffic. For computing CO_2 emissions, rounded constants from the German federal environment agency (Umweltbundesamt 2010) were used; originally, the Umweltbundesamt listed 144 g/km for passenger vehicles, 75 g/km for public transport buses and 72 g/km for city rail. Modern approaches use more elaborate models (Krajzewicz

Table 2. Constants used for computing the discussed indicators.

Transport mode	Max. speed	CO_2	Personal energy consumption	Price
Walking	5 km/h	0 g/km	280 kcal/h	€0/km
Cycling	12 km/h	0 g/km	300 kcal/h	€0/km
Motorized individual traffic	loaded from SUMO	150 g/km	85 kcal/h	€0,45/km
Public transport	as scheduled	75 g/km	170 kcal/h	€0,95/trip

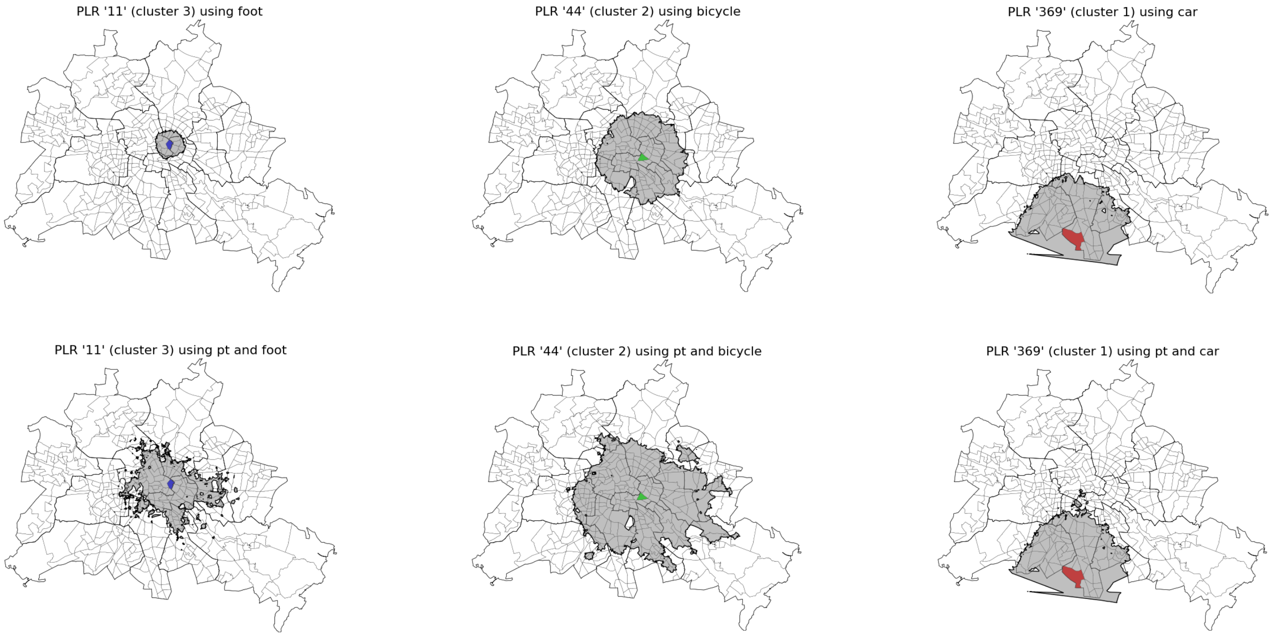

Figure 4. Accessibilities for the selected examples for a travel time of 30 minutes.

et al. 2014) that take into account a vehicle's speed and acceleration profile. However, "UrMo AC" does not support a per-second simulation of a vehicle's movement. Thus, such models cannot be applied here. The price estimation for a passenger car was chosen based upon ADAC's (Germany's major automotive club) price list by randomly choosing a typical car (Audi A3) and rounding the value. Within Berlin, a one-way ticket allows the use of all available public transport modes within the city for two hours, but only in one direction. In the following, the availability of an annual pass is assumed and the final price per ride is computed assuming 20 working days per month and use of the ticket for three trips per day, which results in a single trip price of €0,95. The values for personal energy consumption were collected and cross-checked using different web sites, e.g. http://gesuender-abnehmen.com/.

Given this computation system (software and data), at first a view at the isochrones – here, workplaces accessible within a travel time of 1,800 seconds starting at individual locations – is given for the regarded modes and mode combinations. The time limit of 1,800 seconds was chosen as an approximation of the average travel time to work in Berlin which is about 35 minutes (Beige 2012). The examples shown in Figure 4 were chosen by selecting one of the "planning areas" (PLRs) from the survey where the respective intermodal combination was prominent. One may note artefacts in the south of the PLR in example 3 due to missing information about dwellings outside of the area of the city of Berlin. Figure 4 shows that combining any of the regarded monomodal modes with public transport enlarges the accessible area. This even counts for the fast monomodal "passenger car" mode due to the given speed limits and reduced travel times during peak hours and due to fast city rail and metro connections, which are not affected by other traffic.

This view of sample accessibilities is completed in Figure 5. The travel time is extended to one hour for a broader view and the development of travelled distances in relation to the travel time is shown for all PLRs surveyed. Every dot represents a destination (work location) accessible within the respective travel time and distance. One may note that distance here is the distance travelled, not the beeline distance between an origin and a destination. The lines show the linear regression of travel times against the distances for obtaining a resulting average speed, which is shown in the legend for the respective clusters.

As neither gradients nor waiting at traffic lights are modelled within "UrMo AC" for walking and cycling, the accessed distance grows proportionally with the travel time. This is not the case for driving one's own car, due to the loaded travel times which depend on the situation on the roads. One may note the offsets in travel times and distances when using public transport due to the need to get to the next public transport carrier and waiting for its departure first. All destinations below this offset are accessed faster using a monomodal mode. Overall, public transport is faster than private vehicles and walking, and its speed is again increased when combined with a bicycle carried along the way. The main case where private vehicles outperform public transport services is when using highway connections.

In conclusion, intermodality – here the combination of walking, riding a bike, or driving a car with public transport – within the regarded areas increases travelling speed and even outperforms monomodal use of a private car in most cases. Private vehicles are only faster when travelling longer distances on highways, but are slower in urban regions than public transport. Of course, this is supported by the good public transport offer in Berlin, where both metro and city rail lines have their own track, separated from private traffic. The performances of the modes or mode combinations will differ for other cities.

Beyond travel time

Intermodality is often considered to be healthier for the user and friendlier to the environment in terms of pollutant emissions than motorized individual traffic. To validate this, the performance of intermodal mobility in terms of emissions and personal energy consumption is presented. The settings are the same as already used for determining the accessible space; starting at the PLR's centres, the workplaces accessible within one hour are computed together with the respectively produced CO_2 emissions and the consumed personal energy. The chosen constants for the different modes of transport are given in Table 2.

Starting with emissions, Figure 6 shows the emitted amount of CO_2 in dependence to the travelled distance for each of the modes or mode combinations.

Obviously, non-motorised modes do not emit any pollutants. The highest emissions are produced when using a private vehicle. One should assume that the pollutants emitted when using this mode are even higher, because effects that increase emissions, such as stopping and accelerating at traffic lights or in dense traffic, or running at low speed, are not replicated by "UrMo AC". When combining private vehicles with public transport, the emissions per distance are almost halved in comparison to monomodal use of private vehicles only. The wider spread of emissions arises from different distances travelled by private car and the public transport carrier, respectively, when accessing different destinations. Because of the small velocity of walking, the bigger part of trips using the mode combination walking and public transport is covered within the public transport carrier. Thereby, the emissions are very similar to the used public transport's basic amount of emitted pollutants. This is almost as well the case when combining public transport with cycling, though the distances covered by bike are much higher than the ones covered by foot.

Personal energy consumption for the modes and mode combinations is given in Figure 7. Of course, the active transport modes require the highest amount of personal energy. Again, consumption grows almost proportionally with the distance, because neither gradients nor hindrances along the way are modelled. Public transport has the lowest requirement of personal energy and, thus, intermodal travelling is the least exhausting one. The lower average energy consumption when using public transport in combination with walking compared to the combination with cycling stems from the higher distances covered actively when using the latter combination.

Finally, a quick look at prices will be given. Because the price of public transport does not depend on distance travelled, Figure 8 shows only the development of the price for using one's own passenger car and for combining this mode with public transport. The price for walking and riding a bike is constant at zero while the combinations of these modes with public transport have a constant cost of €0,95. Combining private car with public transport already starts to be cheaper than using a private vehicle only at a distance of 2,375 km.

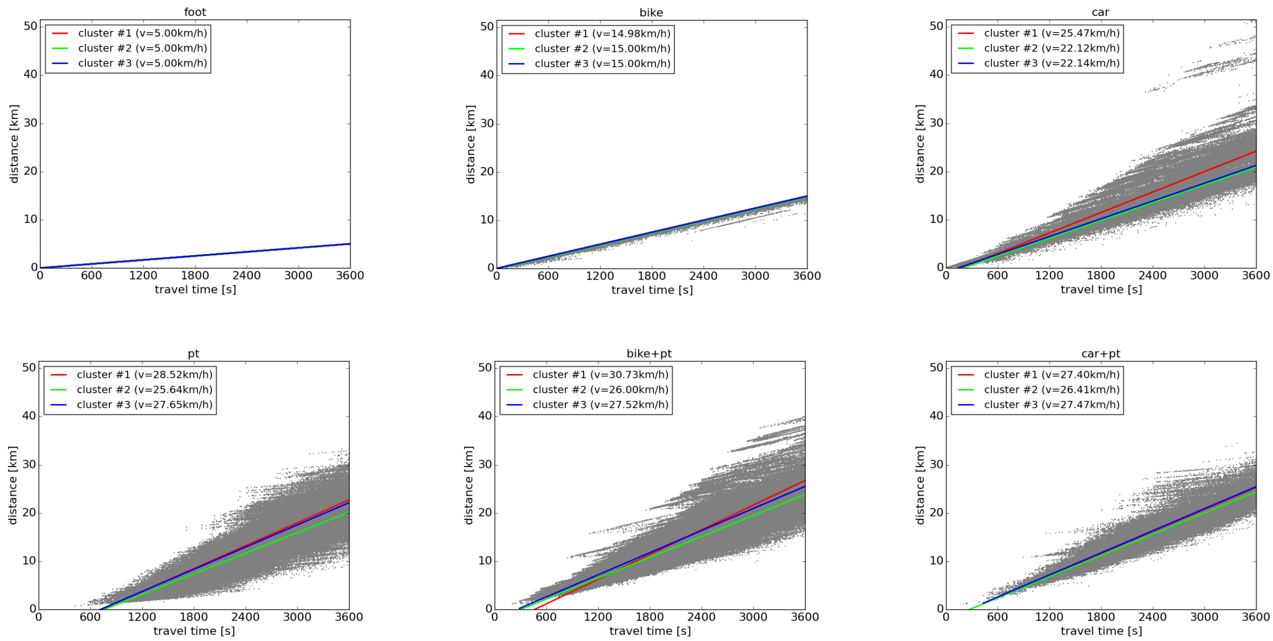

Figure 5. Distance over travel times for trips to workplaces when starting within the regarded PLRs.

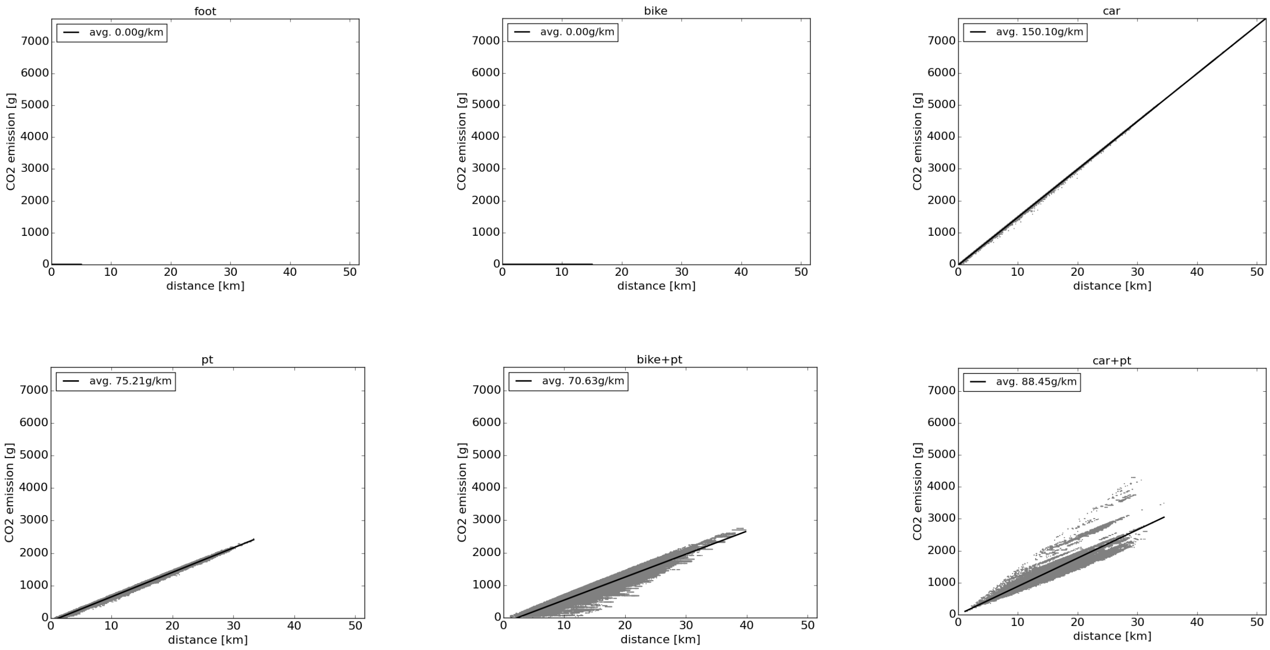

Figure 6. CO_2 emissions in relation to distance for trips to workplaces when starting within the regarded PLRs.

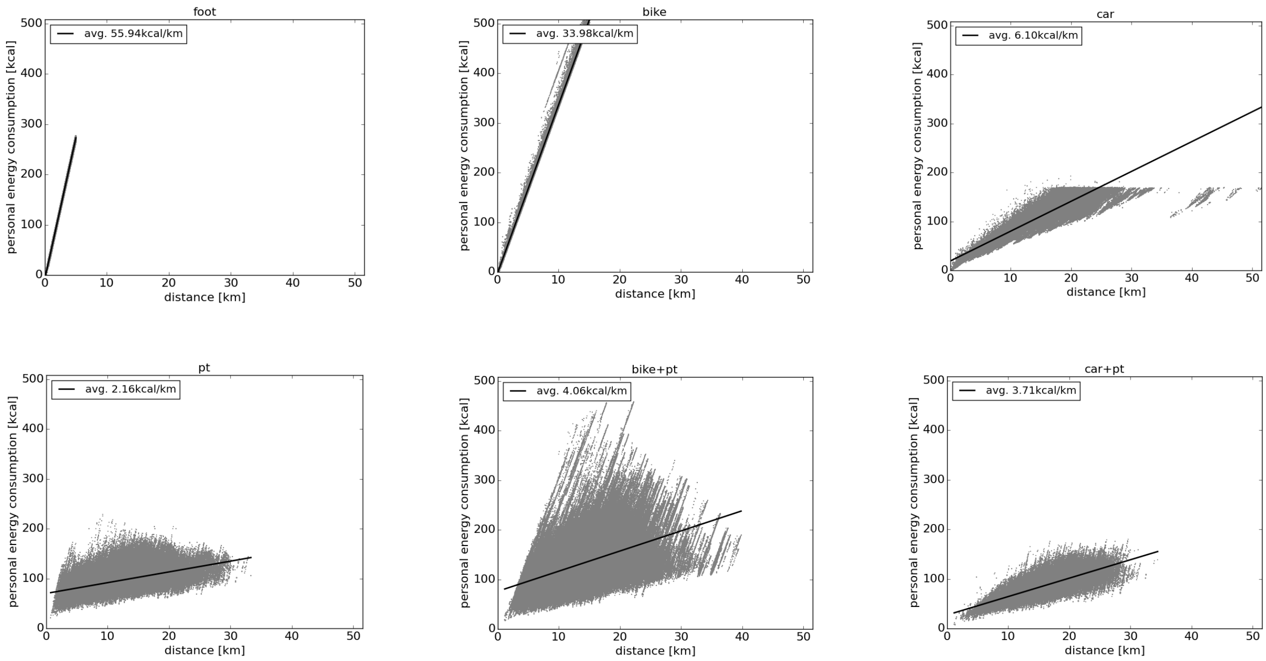

Figure 7. Personal energy consumption in dependence of the distance for trips to workplaces when starting within the regarded PLRs.

Accessibility's influence on mode choice

In a last step, the dependency of mode choice (see Figure 3) within the different clusters on the respective accessibilities is discussed. For this purpose, the development of the number of accessible work places over travel time for each of the modes is shown in the top row of graphs in Figure 9. In the bottom row of Figure 9, the cumulative number of workplaces that can be accessed using the respective mode first is given.

In cluster 2, a significantly high amount of cycling and cycling in combination with public transport was reported. As shown in Figure 9 (centre figure of the top row), both compete with using a private vehicle to a high degree. In addition, the number of accessible workplaces rises steeply within this cluster, meaning that many workplaces can be approached in a relatively short time, which can be assumed to foster the use of an active mode of transport. This explains the higher share of cycling, sometimes in combination with public transport, yet it fails to explain why the share of both these modes is smaller in cluster 3, where both the number of workplaces accessible using these modes is similar to cluster 2 and the amount of workplaces accessed most quickly using a combination of cycling and public transport is even higher.

The share of using the combination of a private car and public transport was highest for cluster 1. Here, the accessibility computation shows that the number of accessible workplaces increases slowly over travel time within this cluster, even when using a private vehicle as the fastest monomodal mode. Workplaces accessible by bike grow slowly and the first ones that can be accessed using a combination of cycling and public transport need a travel time of about 30 minutes. As a result, one could state that using a passenger car is the best option for accessing a large number of workplaces within this cluster. As public transport starts to play a role at a travel time of about 20 minutes, which indicates a delay due to waiting for a carrier, using public transport could be fostered by increasing public transport frequency in these areas.

Summary and conclusions

The focus of this paper was to present results from the Urban Mobility project run by the German Aerospace Center (DLR). The project aims to gain further insights into the topic of intermodality and to discuss whether combining different modes of transport contributes to a more efficient and sustainable urban transport system.

The results of a survey performed within the project's scope were presented first. The findings reveal a relatively high amount of intermodal behaviour, especially when focussing on daily trips to work – around one third of respondents in Berlin used public transport on a daily basis to travel to work.

Subsequently, the performance of monomodal trips was compared against that of their intermodal counterparts for the surveyed planning areas. The investigated indicators include the number of work places accessible over time, the amount of respectively emitted CO_2, the consumed personal energy on the trip, and the price of the journey. The analysis shows that including public transport in journeys extends

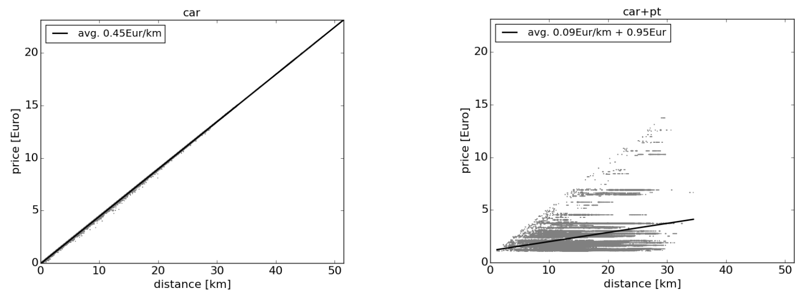

Figure 8. The price in relation to distance for trips to workplaces when starting within the respective PLRs.

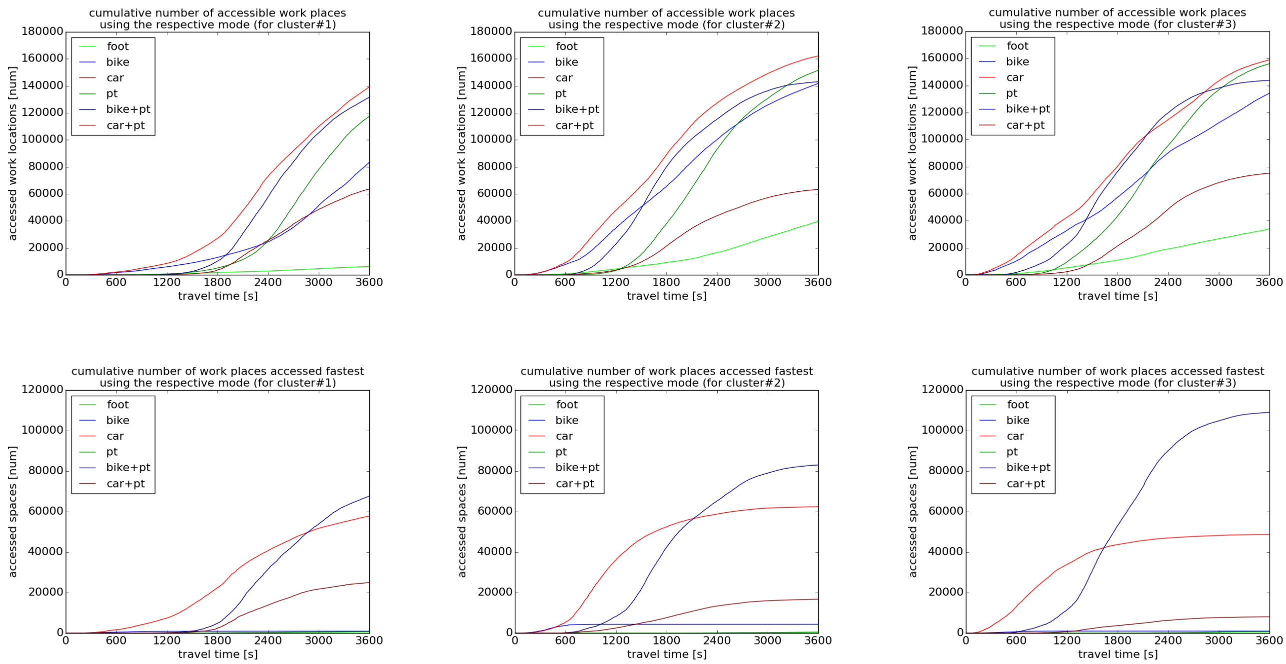

Figure 9. Per-mode accessibilities within the survey clusters; Top: the number of workplaces accessible per mode over time; bottom: the number of workplaces that can be accessed fastest using the respective modes.

the accessible space for all modes, and generates fewer emissions than motorised individual traffic. In addition, it is less exhausting than using active travel modes only, what may increase the willingness to include an active mode as one stage of a trip. Motorized individual traffic is faster and cheaper over very short distances, yet these may be covered easily by bike. The only routes found where using a car is faster and has no replacement are more distant destinations approached via highways. Of course, the performance of intermodality highly depends on the infrastructure and the mobility offers within the respectively regarded area and the reported findings are influenced by the high quality of Berlin's public transport offers to a large degree.

Although the found characteristics of intermodal mode combinations have been reported in earlier studies, the approach presented here delivers concrete numbers that can be compared and is thus a step towards a quantitative benchmarking of intermodal mobility. The approach is transferable to other areas and regards the respective distribution of home and work locations as well as the given transport infrastructure and public transport offers. Yet, the used accessibility computation model is still relatively simple and should be extended, e.g. by a better representation of access and egress times, mainly parking times when using a private car, or by the prices for accessing certain areas as well as for parking within them. As well, regarding the personal energy consumption should be put into a better theoretical context. While travel times, pollutants emission, and the price should be attempted to be minimised, this is not necessarily the truth for the personal energy consumption.

Subsequently presented comparisons of the cumulative number of destinations and workplaces were meant to reveal interdependencies between the characteristics of urban space and the percentage of people choosing an intermodal combination of public transport and another mode of travel. Although some hints could be found, which show that mode choice depends on the distance to the desired location, other socio-demographic and infrastructure attributes would have to be included to provide a mode choice model.

It may be mentioned that using contour accessibility measures does not take into account the users' preferences and their possibilities to use certain transport modes. Nonetheless, the authors assume that such an approach allows the performance of intermodality to be measured in a clear, concrete way, without diffusing it with additional – often only assumed – variables. It is thereby valuable for describing an area's mobility offers rather than the respective users' behaviour. As well, it may be deployed for determining which offers – may they consist of new public transport lines or new regulations regarding the entrainment of bikes in public transport carriers – would increase an area's accessibility.

Further steps that shall strengthen the understanding of both, intermodal behaviour and intermodality's importance, will be undertaken within the project. This includes further investigation of the influences that foster intermodality, mainly including the socio-demographics of the population, the modelling of intermodal behaviour in demand and traffic flow models, and the inclusion of further cities in the evaluations for obtaining a comparative view.

References

Ahrens, G.-A.; Klotzsch, J. & Wittwer, R. (2014): Auto nutzen, statt besitzen. Treiber des multimodalen Verkehrsverbunds. In: Zeitschrift für die gesamte Wertschöpfungskette Automobilwirtschaft 17 (2), p.6–21.

Beige, S. (2012): Analyses of commuting distances and times in the household context: The case of Berlin. 13th International Conference on Travel Behaviour Research , Toronto 15–20th July.

Cao, X.J.; Mokhtarian, P.L. & Handy, S.L. (2009): The relationship between the built environment and nonwork travel: A case study of Northern California. In: Transportation Research Part A: Policy and Practice 43, 5, p. 548–559.

Chlond, B. (2013): Multimodalität und Intermodalität. In: Nicht weniger unterwegs, sondern intelligenter? Neue Mobilitätskonzepte, p. 271–293.

Chlond, B. & Manz, W. (2000): INVERMO – das Mobilitätspanel für den Fernverkehr. In: Deutsche Verkehrswissenschaftliche Gesellschaft (Hrsg.), Dynamische und statische Elemente des Verkehrsverhaltens – Das Deutsche Mobilitätspanel. Karlsruhe, Schriftenreihe der Deutschen Verkehrswissenschaftlichen Gesellschaft, Reihe B 234, p. 203–227.

Commission Of The European Communities (EC) (1997): Intermodality and intermodal freight transport in the European Union.

Dacko, S. G. & Spalteholz, C. (2014): Upgrading the city: Enabling intermodal travel behaviour. In: Technological Forecasting and Social Change 89, p. 222–235.

Deutsches Zentrum für Luft- und Raumfahrt (DLR) (2015): Projekthomepage „Urbane Mobilität": www.urmo.info.

Diaz Olvera, L.; Guézéré, A.; Plat, D. & Pochet, P. (2014): Intermodality in a context of poor transport integration. The case of Sub-Saharan African cities. Transport Research Arena (TRA) 5th Conference: Transport Solutions from Research to Deployment, Paris 14–17th April.

Follmer, R. & Scholz, J. (2013): Mobilität der Zukunft – bedürfnisorientiert statt technikfixiert. In: Internationales Verkehrswesen 65 (3), p. 54–57.

Gebhardt, L.; Krajzewicz, D.; Oostendorp, R.; Goletz, M.; Greger, K.; Klötzke, M.; Wagner, P. & Heinrichs, D. (2016): Intermodal urban mobility: users, uses, and use cases. 6th Transport Research Arena. Transportation Research Procedia, Volume 14, p. 1183–1192.

Hall, I. (2016): Intermodality: a key element for urban mobility strategies? In: Eurotransport – Intermodality supplement, Volume 14, Issue 2, p. 9–11.

Heinrichs, D. & Oostendorp, R. (2015): Mobilität – in Zukunft intermodal? In: ATZ extra. VDI-FVT-Jahressonderveröffentlichung, p. 18–21.

Heinrichs, M.; Krajzewicz, D.; Cyganski, R. & von Schmidt, A. (2016): Disaggregated car fleets in microscopic travel demand modelling. In: The 7th International Conference on Ambient Systems, Networks and Technologies (ANT 2016).

Institut für Mobilitätsforschung (Ifmo) (2011): Mobilität junger Menschen im Wandel –multimodaler und weiblicher. In: Ifmo-Bericht der BMW Group.

Jarass, J. & Oostendorp, R. (2017): Intermodal, urban, mobil – Charakterisierung intermodaler Wege und Nutzer am Beispiel Berlin. In: Raumforschung und Raumordnung 75. DOI: 10.1007/s13147-017-0478-z.

Jones, W.B., Cassady, C. R., Bowden, R.O. (2000): Developing a Standard Definition of Intermodal Transportation. In: Transportation Law Journal 27 (3), p. 345–352.

Knie, A. (2013): Was bewegt uns? Veränderte Nutzungspräferenzen und Angebotsformen im Verkehr: Chancen und Risiken für die Energie- und Verkehrswende. In: Nicht weniger unterwegs, sondern intelligenter? Neue Mobilitätskonzepte, p. 256–271.

Köhler, K. & Heinrichs, M. (2014): Das Elektronische Wegetagebuch – Chancen und Herausforderungen einer Automatisierten Wegeerfassung Intermodaler Wege. In: Schelewsky, M.; Jonuschat, H.; Bock, B. & Stephan, K. (Hrsg.): Smartphones unterstützen die Mobilitätsforschung. Neue Einblicke in das Mobilitätsverhalten durch Wege-Tracking. Wiesbaden, p. 25–46.

Krajzewicz, D.; Erdmann, J.; Behrisch, M. & Bieker, L. (2012): Recent Development and Applications of SUMO – Simulation of Urban Mobility. International Journal On Advances in Systems and Measurements, 5 (3&4), p. 128–138.

Krajzewicz, D.; Hausberger, S.; Wagner, P.; Behrisch, M. & Krumnow, M. (2014): Second Generation of Pollutant Emission Models for SUMO. In: SUMO2014 – Second SUMO User Conference, Berlin, 15–16th May.

Krajzewicz, D. & Heinrichs, D. (2016): UrMo Accessibility Computer – A tool for computing contour accessibility measures. In: SIMUL 2016, 8thInternational Conference on Advances in System Simulation, p. 56–60.

Kuhnimhof, T.; Buehler, R.; Wirtz, M. & Kalinowska, D. (2012): Travel trends among young adults in Germany: increasing multimodality and declining car use for men. In: Journal of Transport Geography 24, 443–450.

Last, J. & Manz, W. (2002): Notions of Intermodality in Inter-City Passenger Transport. In: Proceedings of the International FOVUS Symposium, Stuttgart.

Litman, T. (2003): Measuring Transportation: Traffic, Mobility and Accessibility. In: ITE Journal, Vol. 73, No. 10 (October 2003), p. 28–32, http://www.vtpi.org/measure.pdf.

Nobis, C. (2007): Multimodality: Facets and Causes of Sustainable Mobility Behavior. In: Transportation Research Record 2010, 35–44.

Scheurer, J. & Curtis, C. (2007): Accessibility Measures: Overview and Practical Applications, urbanet WORKING PAPER No. 4, Curtin University of Technology.

Senatsverwaltung für Stadtentwicklung und Umwelt Berlin (2014): Mobilität der Stadt. Berliner Verkehr in Zahlen 2013. http://www.stadtentwicklung.berlin.de/verkehr/politik_planung/zahlen_fakten/ download/Mobilitaet_dt_komplett.pdf (12.11.2015).

Thomas, C. & Schweizer, T. (2003): Zugang zum öffentlichen Verkehr: Der Fussverkehr als „First and Last Mile“. In: strasse und verkehr | route et trafic 10, p. 16–19.

Ubbels, B.; Palmer, D. (2013): Conceptual framework: key intermodality factors. City HUB project. http://www.cityhub.imet.gr/Portals/0/D2%202_Conceptual%20framework_key%20intermodality%20factors%20(2).pdf (19.10.2016).

Umweltbundesamt (2010): CO2-Emissionsminderung im Verkehr in Deutschland. https://www.umweltbundesamt.de/sites/default/files/medien/461/publikationen/3773.pdf (20.02.2017).

Van der Hoeven, F. ; Van Nes, Ak. & Van der Spek, S. (2013): NODES. State of the Art. Available at: http://www.nodes-interchanges.eu/documents/2014/05/nodes_wp2_d2-3_final-3.pdf (19.02.2016).

Verband Deutscher Verkehrsunternehmen (VDV) (2013): Positionspapier Mai 2013; Der ÖPNV: Rückgrat und Motor eines zukunftsorientierten Mobilitätsverbundes.

Von der Ruhren, S. & Beckmann, K.J. (2005): Bestimmung multimodaler Personengruppen. In: Stadt Region Land 78, p. 115–127.

Yeh, C.-F. (2008): A study on feasibility of passenger intermodal transport in city of the developing world. Conference paper: Codatu (Coopération pour le Dévelopement et l'Amélioration des Transport Urbains et Périurbains – Cooperation for Urban Mobility in the Developing World) XIII, Ho-Chi-Minh-Stadt, 11–14th November.