COMPARISON AND ASSESSMENT OF LARGE URBAN ROAD NETWORKS-
A CASE STUDY

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Abstract

This paper presents the results of a case study of road infrastructure assessments of two large German cities, namely Berlin and Munich. The major aim is to investigate the quality of the main road network as a whole and to identify infrastructure deficiencies. The used methodology is based on integral assessment criteria derived from comprehensive traffic monitoring data. These data are collected by using taxis as probe vehicles.

1. INTRODUCTION

Assessments of complex urban road networks are recently feasible triggered by comprehensive sets of area-wide traffic monitoring data. Nevertheless, urban planers and traffic engineers still do not have appropriate tools to evaluate an urban road network as a whole. They normally focus on few important corridors and major junctions in the city measuring the traffic throughput across arterials and travel times along selected routes. Also, traffic engineers often optimize traffic light signals at major junctions [De Schutter 1996] just with respect to one route completely neglecting all the others. However, urban road networks are complex structures with a high degree of interdependencies between different edges of the network. For example, changing the capacity at one part of the network might significantly affect other, even fairly remote, areas. To evaluate infrastructure measures or to compare the road network quality of different cities or districts, a number of integral evaluation methods are desirable. The methods described below are based on comprehensive long-term traffic monitoring for the area to investigate. Common traffic measurements like induction loops or video observations are not capable to supply sufficient data sets for this task. Therefore, we utilise positioning data of taxis, so-called floating car data (FCD), as traffic data provider. We present a road network intercomparison for the cities of Berlin and Munich, Germany. Over the last two years we received about hundred million positioning data sets from several hundred taxis of these cities. The results of the comparison allow to rate the road infrastructure of these cities and to relate the current road transport demand to the capacity of the network, pointing out bottlenecks of the available infrastructure or management deficiencies.

2. CITY ROAD NETWORK SPEED MATRICES

The evaluation methods are based on averaged travel time matrices for all major roads of the region of interest. The underlying data are collected by a fleet of probe vehicles, e.g. taxis. The probe vehicles move within the normal flow of traffic, determine and log or transmit their positions detected by GPS signals in sufficiently small time intervals. Mapping the positioning data to a digital road map of the area allows the estimation of link travel times and the construction of time dependent speed matrices for the road network driven by the probe vehicles. The data are processed to hourly averages separated by each week day. In contrast to stationary traffic sensors we cannot derive information about vehicle fluxes. Nevertheless, we can estimate average travel times on each road segment which was cruised by a taxi during the period of interest. Exploiting a considerable large fleet, in our investigation a fleet of several hundred taxis with high yearly mileage, this allows the computation of time-dependent velocities for a representative part of the road network [Kühne 2003]. Meanwhile, several million probe vehicle data have been collected during the last three years for a couple of large European cities, e.g. Berlin, Vienna, Nuremberg, Munich, Stuttgart and Regensburg. In this paper we present results for the cities of Berlin and Munich.
Applying a map matching and routing algorithm to assign the taxi position data to segments given by a digital road map (NAVTEQ road maps have been used for this study) leads to road segment velocities. The map of road network speeds at morning rush hour on working days for Berlin and Munich area is shown in Fig. 1. It is clearly visible that low speed areas are especially in the vicinity of the city centre, whereas higher speeds can be expected at suburban roads and on the city freeways.

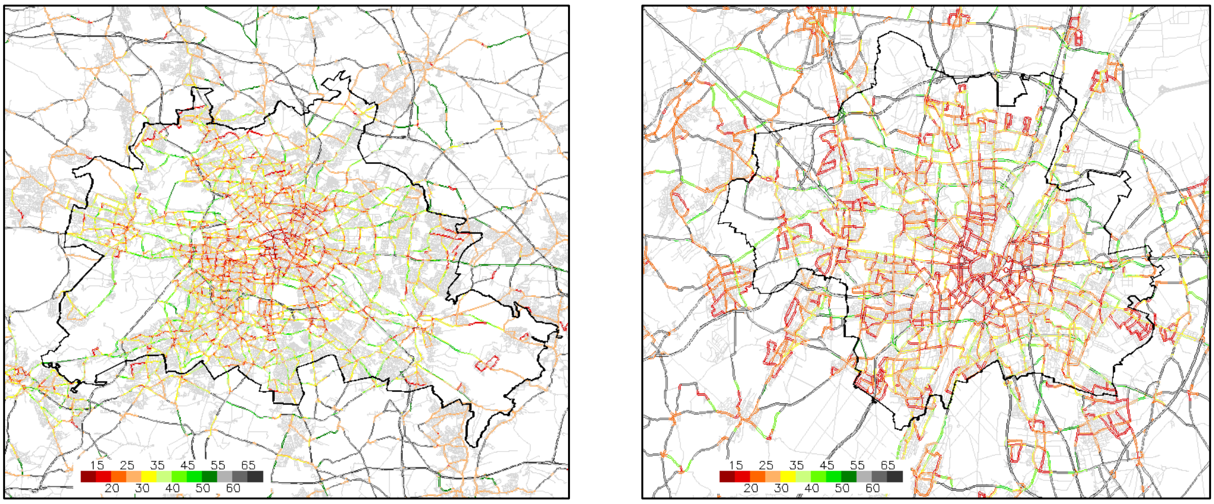


Fig. 1: Link segment speed in [km/h] at morning rush hour on working days for Berlin (left) and Munich (right)

Besides integral studies of the whole network the data also allow a detailed analysis of individual parts of the network where data penetration is adequate. For example, Fig. 2 shows the average speed on road segments of a major traffic circle in Berlin. During the morning rush hour (left panel) a considerable low velocity is indicated on the southern road Hofjägerallee in driving direction north. At the evening at 8 p.m. this congestion disappeared on this part of the road (right panel).

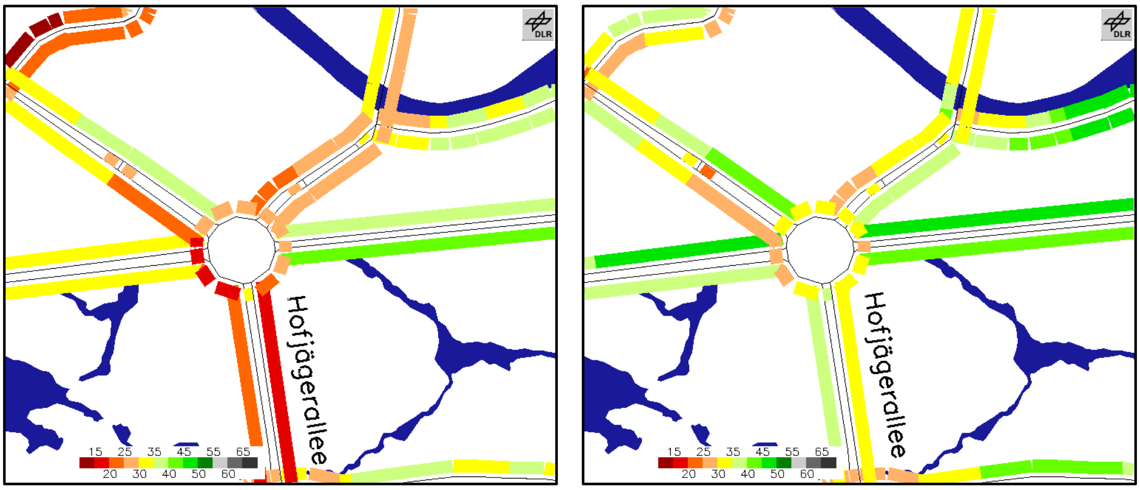


Fig. 2: Speeds [km/h] on network segments on working days for a major junction in Berlin at 8 a.m. (left) and 8 p.m. (right)

The daily courses for all week days are given in Fig. 3. In contrast to data collected by induction loops, the velocities of the daily course are not point values but represent the average velocities for all lanes of a tiny street segment in one direction, on average a 70 m long piece of road Hofjägerallee. In Fig. 3 (left panel), a very pronounced rush hour velocity breakdown in the morning and during the evening is visible on working days. On Friday, the evening rush hour starts even earlier and ends also earlier. On Sunday the breakdowns vanish. In the other driving direction of the same road (right panel), only a strong morning rush hour speed collapse is visible on working days. The assessment quantities described below are based on this time dependent small scale velocity data.

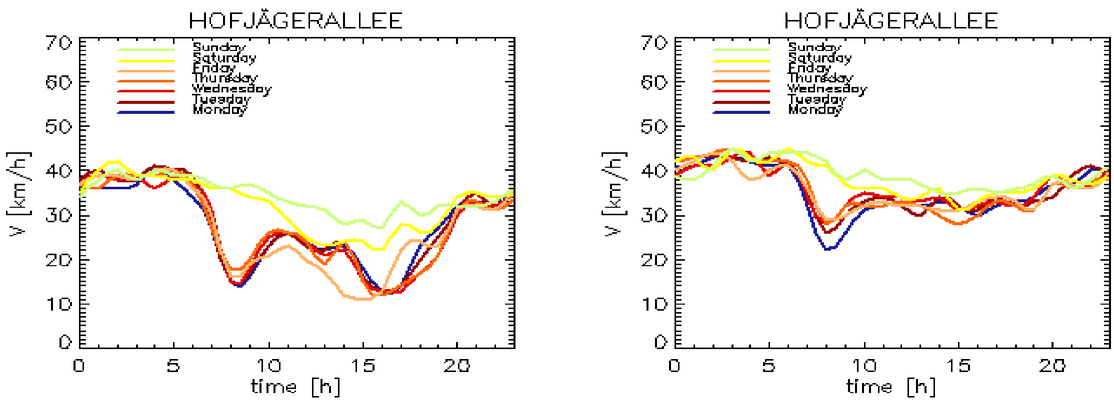


Fig. 3: Daily course of velocity for all week days for road segment Hofjägerallee in driving direction north (left) and driving direction south (right)

3. AVERAGE ROAD NETWORK SPEED

An elementary integral network quality indicator which can be computed is the daily course of the average speed of the road network of the cities. The absolute value of the network speed is not of much interest because its value strongly depends on the specific road network constitution, e.g. the road kilometres which are city freeway etc. A fraction of roads with higher speed allowance and high capacity may easily shift the average speed to much higher values. On the other hand, the daily course of the average network speed can give first insights into typical network characteristics and allows first conclusions about the net utilization and, at least implicitly, about the mobility behaviour of the users. The daily course for a typical working day (Monday to Thursday average) is shown in Fig. 4. Although this course is quit similar for both cities with variations between 29 km/h during rush hour events and 43 km/h at the early morning some differences are visible.

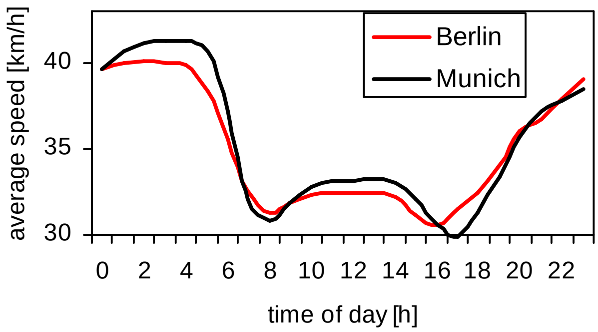


Fig. 4: Daily course of the average network speed of Berlin and Munich on a typical working day, main roads only

The rush hour drops are more pronounced for Munich, whereas the speed between the negative minima of the curve is lower for Berlin. The overall variation of the average speed is higher in Munich, and the velocity drops at are always steeper. It is interesting to note that the evening speed minimum in Munich is at least one hour later in comparison to Berlin, although the morning minima occur nearly at the same time. This might have to do with the more intensive commuter traffic in the Munich region which tends to persist during late afternoon.

4. SPEED HISTOGRAMS OF ROAD NETWORKS

To characterize the road network, the distribution of the roads into speed classes (fraction of the road network in a certain speed class) can be used. To compute this quantity, only the main road network including city freeways inside the city limits has been considered. Smaller streets within residential areas are often intentionally slowed down to increase safety and to avoid extensive noise production. Therefore, including such streets in the analysis can lead to misinterpretation because it cannot be decided whether the estimated low speed is due to high traffic volumes or due to speed limits or structural measures.

Based on this time dependent speed information of most important links of the road network some elementary statistical investigations give valuable measures of the overall behaviour of the road network. The calculated fraction of the total road network length in a given speed category derived by accumulated FCD-based segment velocities gives a descriptive picture of the typical time-dependent integral network characteristic. To account for time-dependent driving behaviour of the probe vehicles (the distribution of driven kilometres between different road types differ sometimes considerably), the estimated quantities of a certain road type are weighted by the fraction of travelled kilometres on this particular street type and its total occurrence in the region of interest.
The speed classes are separated by 5 km/h steps and speed class identifier describes the upper speed limit of this speed class. As an example, the distribution of the percentage of road kilometres within velocity classes for a typical working day at 8 a.m. in Berlin and Munich is given in Fig. 5. The most likely velocity in both cities at 8 a.m. is between 25 and 30 km/h.

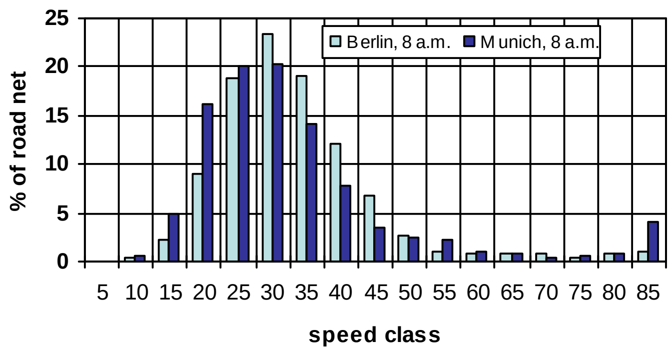


Fig. 5: Percentage of road length per speed class for Berlin and Munich at 8 a.m. for a typical working day

There is a clear tendency towards lower velocity classes in Munich in comparison to the city of Berlin. The fraction of the road network length with speeds below 20 km/h is nearly doubled in comparison to Berlin. These parts of the network can be considered as congested and cover about 11 % of the total main road network of Berlin, whereas the figure is about 20% for Munich.
To analyse the change of the distribution we consider the difference to the free network case. The free network case is the situation where a driver is not affected by anybody else driving and its speed is only determined by the constructional conditions of the roads and the car, the traffic lights, speed limits and drivers ability and willing to go by a desired speed. Again, having a considerable data set of different drivers during late night the estimated traffic state can be used as a close approximation. In this study we use the velocity class distribution at 4 a.m. as a reference. At this time a rather undisturbed traffic can be assumed on the main road network. Fig. 6 shows the difference of road length in the chosen speed classes at the morning and evening rush hours at 8 p.m. and 4 a.m. on working days for Berlin and Munich, respectively.
Besides total network assessment these investigations can be performed on subnetworks as well. Running the analysis for an isolated area allows finding out infra-

structure deficiencies in particular regions. This allows the identification of the part of the network suffering from regular heavy congestion, e.g. during peak traffic hours.

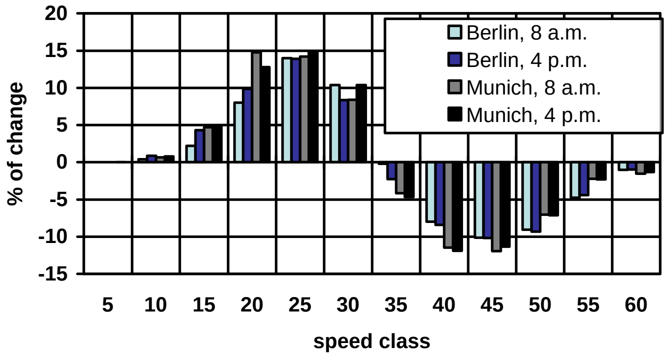
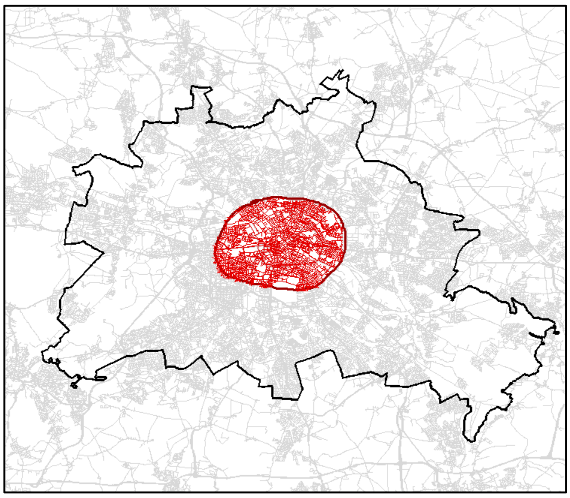


Fig. 6: Percentage of change of the road length distribution of speed classes with respect to the free network situation during morning and evening rush hour on working days in Berlin and Munich

Normally, inner city areas are more congested in comparison to suburban areas. Additionally, most cities have certain zones with traffic related problems. This method may also be beneficial for analysing the effect of infrastructure or traffic management measures carrying out before-and-after considerations.
Such sub-networks can be defined by simply selecting administrative district boundaries or manually by the investigator marking desired areas onto the city road map.
In Fig. 7 the city centre areas of Munich and Berlin have been somehow arbitrary manually selected for further analysis.



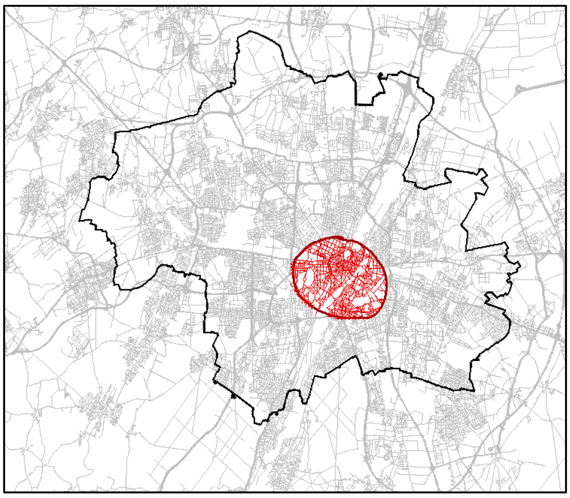


Fig. 7: Selected city centre road sub-network for Berlin (left) and Munich (right)

The further investigation takes into account the total city networks as well as the selected zones. In Fig. 8, the shift of the velocity class representation of the network during morning and evening rush hour at 8 a.m. and 4 p.m. in comparison to the 4 a.m. values is shown.

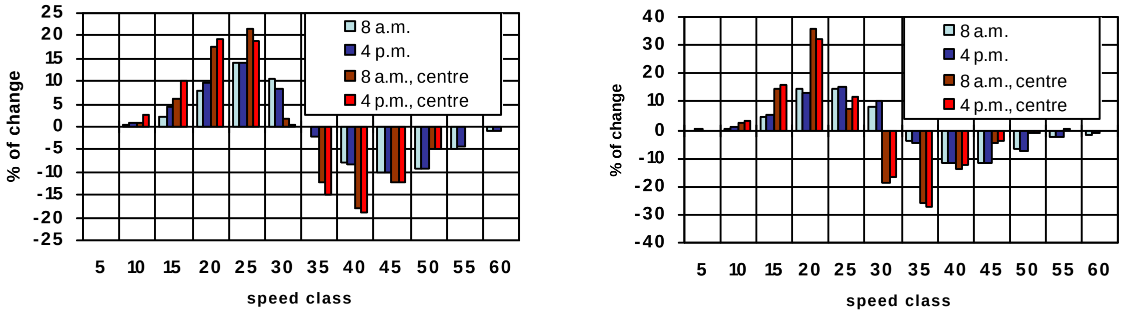


Fig. 8: Percentage of change of the road length distribution of speed classes with respect to the free network situation during morning and evening rush hour for working days, Berlin city road network and city centre (left) and Munich (right)

A tremendous shift towards low speed classes can be seen in general. Areas with a predominant fraction of speed classes below 20 km/h can be considered as congested city areas. For Berlin, these classes show an increase of about 15% for the city and roughly about 30% for inner city areas which means a proportional increase of the road network length in these speed classes. The situation at 4 p.m. tends to be more congested then during the morning rush hour at 8 a.m. in both the total city area and the inner city region.

For Munich, the speed shift towards low velocity classes is much more enhanced. The shift towards congested velocity classes is about 20% and within the marked inner city region around 45%. Nearly the whole inner city area of Munich can be considered as congested during rush hour periods. It should be noted that the selected Munich centre area is much smaller then its Berlin pendant and covers only the very central part of the old city which enlarges the mentioned effect. Nevertheless, already the comparison between the total city area of Berlin and Munich which is given in Fig. 6 indicates a much larger rush hour velocity decrease for Munich in comparison to Berlin.

In Munich, the effect seems to be higher during the morning rush hour, whereas it’s the opposite in the Berlin case study. However, as already mentioned above, the evening minimum for Munich is at least one hour later and taking the 5 p.m. results would change that picture indicating a worse situation at afternoon too.

The commuter traffic in Munich is much higher in comparison to Berlin. Munich inner city apartment prices have risen dramatically during the last years whereas they stay more stable in Berlin, and there is a much more prosperous industry in the Munich region. Industry and residential districts around Munich cause a high travel demand. During the peak rush hours, most of the roads to and from the Munich city centre are heavily congested. Additionally, the busy Munich airport is another source of traffic. Consequently, the traffic demand has been growing quite fast during the last decade but there are rare possibilities at least in inner city regions to enlarge the road infrastructure.

5. ACCESSIBILITY ANALYSIS

Knowledge about accessibility of districts of cities is essential for transportation and urban development planning issues, but plays also a crucial role for many companies. When companies choose the location for a new factory, office or store its accessibility by individual traffic is one major criterion. That applies to private persons

in a similar way when they look for a new home. Obviously, the accessibility of districts of cities is highly important for the design and dimensioning of new infrastructure, in traffic planning as well as in development planning [Spiekermann 1994, Halden 2000, Schürmann 2000]. Accessibility by car is mainly described by travel time, but also includes e.g. the availability of parking space, parking costs. The later quantities are not considered in the following study.
Using the FCD described above the accessibility by car in terms of travel time can be estimated for each part of the road network with high accuracy according to day of week and time of day. For this the travel times from a selected site to each knot in the road net are calculated. A single source shortest path algorithm like Dijkstras algorithm [Dijkstra 1959] can be used for that. It has to be carried out only once per scenario, the computational effort is low. The travel times along the roads are estimated based on FCD. Locations showing the same travel time from or to a selected destination form a set of isochrones. Analysing the shape of the isochrones eases tremendously the identification of road infrastructure mismatch even for complex urban networks. As an example, Fig. 9 shows the accessibility of the Brandenburg Gate, Berlin, for a typical Monday, 8 p.m.

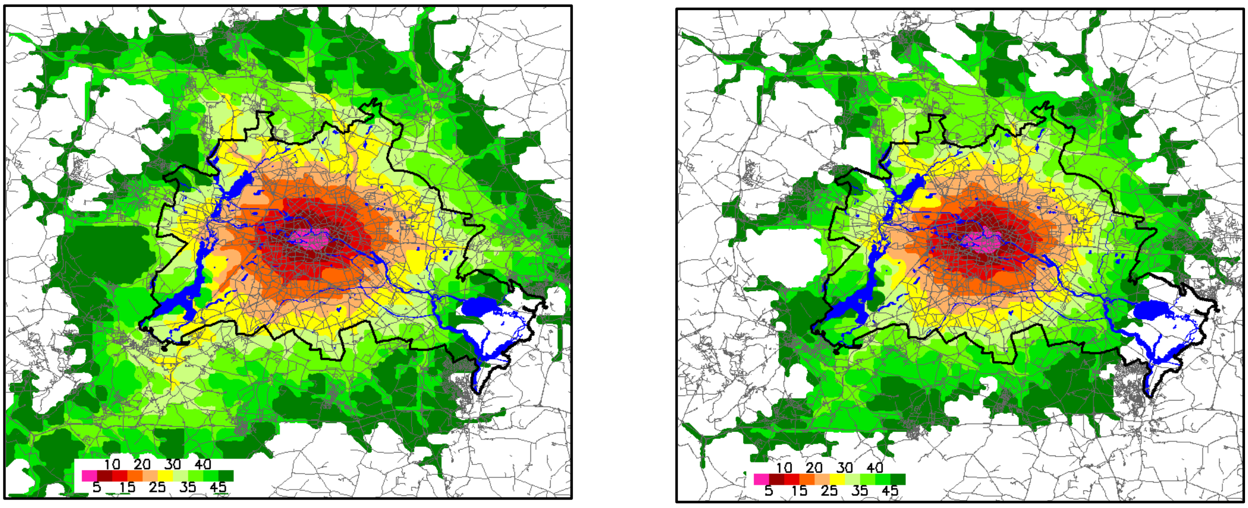


Fig. 9: Isochrones of travel time in minutes from (left) and to (right) the Brandenburg Gate, Berlin, on a typical Monday, 8 p.m.

It is clearly visible that during the morning rush hour the average travel times towards the city center (right panel) of Berlin are significant longer then in opposite direction (left panel). Furthermore the noncircular shape of the isochrones indicates asymmetries in the quality of road infrastructure, especially between the southwest and southeast part of Berlin. This may be a result of and/or a cause for the different population densities in these areas. Well defined is also the influence of the city hi-freeway A100 which approaches the city center from north-west and south-west. The calculated accessibility by road can be matched with socio-demographic data like the population density or/and the numbers of companies and work places. In our investigation, a set of travel time isochrones for a dense net of selected points are overlaid with population density data (see Fig. 10 left). This allows the estimation of the number of persons which are able to reach a specified location in a given time. That is an important information for all facilities with visitor/customer traffic, especially during settlement planning. If a facility is commonly used by people who can access it e.g. within 10 minutes by car, a map as shown in Fig. 10 (right) can be generated where the colored zones represent the numbers of persons who can reach the areas within a given time period, depending on time of day and day of week.

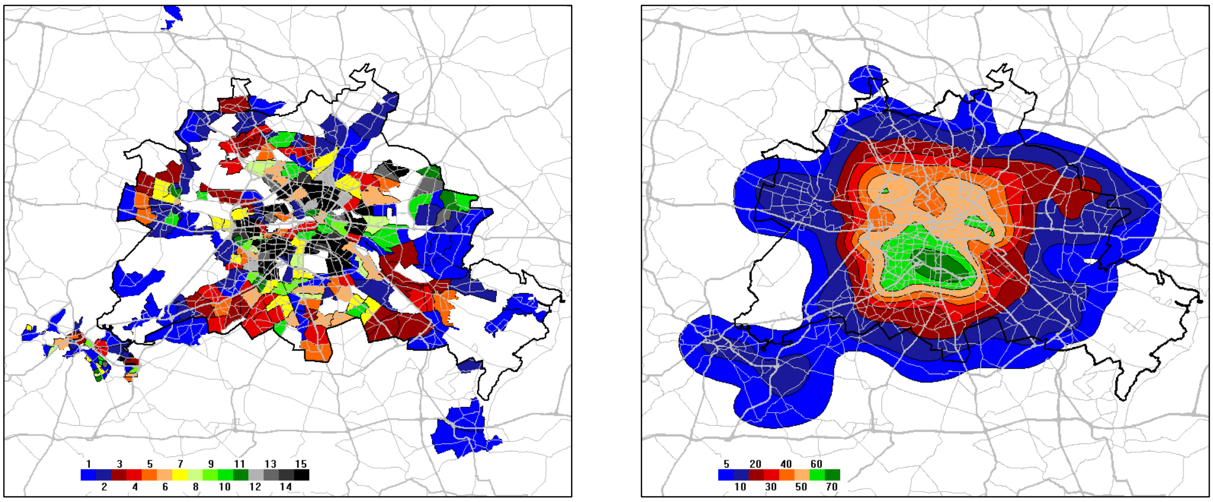


Fig. 10: Berlin population density [10^3 / km^2] (left) and number of persons [10^4] who can reach that location by car within ten minutes (right, Friday, 4 p.m.), population density data from infas GEOdaten GmbH, Bonn, Dec. 2001

The map shows that the city center is reachable by car from significantly more people (> 700,000 within ten minutes) than the suburbs, which makes the location favorable for the settlement e.g. of retail industry, but also for public facilities like theatres etc.. It also shows that the course of the city freeway A100 significantly increases the accessibility of the affected districts.
Instead of total population densities the density data of specific groups of “persons of interest” (e.g. age-groups) can be used, as far as available.
The proposed method to determine the number of persons in the catchment area of a facility is more accurate then using conventional approaches because of the profound knowledge of travel times from FCD. Attention should be paid to the amount of additional traffic induced by the facility itself, which may reduce the estimated accessibility of its location.

Conclusions

The presented methods for an integral urban road network assessment can be recommended for urban regions having a reasonable complete knowledge of time-dependent road speeds. These data might be obtainable with a justifiable effort by probe vehicles only. On the basis of these data, statistical evaluation, comparison and trend analysis of the vehicular quality of urban networks and freely definable sub-networks are feasible with a high degree of reliability. This is proposed to be a valuable tool for urban planers as well as for a lot of businesses with demand of easy and fast access to their facilities.
Nevertheless, some misinterpretations may occur caused by data collected from special fleet probe vehicles, e.g. taxis. Future increase of data penetration using different kinds of car fleets will help to overcome this shortcoming.

It has to be mentioned that it is certainly not the aim of the traffic related urban planning to speed up the traffic within cities. But avoiding congestion is an important issue because besides the economic losses due to longer travel times it has serious impact on the environment and living quality of the cities. Nowadays, the problem of city traffic congestion can be hardly solved due to road infrastructure measures. This might be still possible at few critical locations. In general, the only feasible solution to preserve mobility and living quality of large cities is to enhance the attraction of the public transport system on one hand, to take intelligent traffic management measures on the other hand and to reduce the traffic by creating and preserving adequate urban structures. In this context, the discussed integral road network assessment methods for cities can be used for analysing the current traffic situation and to survey year to year trends as well as evaluating the influence of urban planning and traffic management measures.
Finally, it needs to be mentioned that the proposed road infrastructure quality measures are only focused on the technical issues of vehicular traffic. Obviously, more comprehensive investigations considering environmental, safety and social aspects as well as multimodal transport have to be included for planning and evaluation of urban mobility.

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