# Searching for Parking in GPS Data

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## Abstract

Parking search is widely accepted to be a significant contributor to congestion in city centers. The high parking occupation on Saturdays in Zurich suggest this also an issue there. Raw person-based GPS data from Switzerland and especially Zurich is analysed regarding parking search characteristics. For processing the POSDAP routines developed at the institute are extended. The descriptive analysis considers driving times and distances but also subsequent walk stages. Results suggest that search traffic is a local phenomenon and not as dramatic for the overall city as expected.

## Keywords

GPS, parking, post-processing, POSDAP

# 1 Introduction and Related Work

Parking search is regarded as a significant contributor to congestion in city centers (see e.g., Shoup (2005)). Understanding, modeling and managing it, e.g., with parking policies, are thus important tasks (see e.g., Marsden, 2006, Topp, 1991, Feeney, 1989, Baier *et al.*, 2000, Glazer and Niskanen, 1992, Miller and Everett, 1982, van der Waerden *et al.*, 2009). However, parking search behavior is complex as it depends on traffic circumstances, trip purpose, individual strategies, the driver's knowledge of the area and more. Hence, search start is latent and even the driver may not know it exactly. To survey and quantify search behaviour is thus difficult (Kipke, 1993, Arnott and Inci, 2005), especially time and distances reported in interviews are biased as estimations are probably influenced by traffic conditions, trip purpose but also the frustration level of drivers.

Survey approaches used so far were laboratory experiments (e.g., Bonsall *et al.*, 1998), stated preference surveys (Axhausen and Polak, 1991, Weis *et al.*, 2011, Golias *et al.*, 2002, van der Waerden *et al.*, 2006, 1993, Widmer and Vrtic, 2004) or field observations such as riding with a searcher (Laurier, 2005) or following a car until it is parked (Wright and Orram, 1976). Modeling approaches range from discrete choice models, numerical models, Possibility Theory to simulations (Gillen, 1977, 1978, Hensher and King, 2001, Arnott *et al.*, 1991, Arnott and Rowse, 1999, Anderson and de Palma, 2004, Benenson *et al.*, 2008, Gallo *et al.*, 2011, Thompson and Richardson, 1998, Dieussaert *et al.*, 2009, Kaplan and Bekhor, 2011, Axhausen, 1988, Young, 1986, Young and Thompson, 1987, Maley and Weinberger, 2011, van der Waerden *et al.*, 1998, Young and Weng, 2005, van der Waerden *et al.*, 2002).

A relatively new and very rich data source to complement these surveys are GPS data. But the huge amount of data requires sophisticated and automated post-processing procedures. It is mainly collected to get more complete and accurate travel diaries (e.g. Yalamanchili *et al.* (1999), Draijer *et al.* (2000), Wolf *et al.* (2001), de Jong and Mensonides (2003), Auld *et al.* (2009), Marchal *et al.* (2011), Oliveira *et al.* (2011), Rieser-Schüssler *et al.* (2011)). Lately, GPS data are also used to observe more specific travel behaviour; Moiseeva and Timmermans (2010) focus on activity patterns in retail areas. The work most related to this paper is Kaplan and Bekhor (2011) who investigate the joint decision of parking type and parking-search route. To observe the actual route taken they intend to use GPS data collected in Tel Aviv. Using GPS data to observe parking search data has the advantage over interviews and questionnaires that time and distance calculations are objective and not estimated.

For this paper POSDAP (POSDAP, 2012), an open source GPS data analysis framework originating from the work described in Schüssler and Axhausen (2009b) and Rieser-Schüssler *et al.* (2011) is used and it is further developed to extract parking search relevant characteristics. As part of an ongoing Swiss project at authors' institute, a person-based Zurich and Geneva data set is analysed (see Section 3.1).

This report is structured as follows. In Section 2 the research goal is specified, Section 3 describes definitions and methods used and Section 4 discuss the findings and in 5 conclusions and future work are described.

# 2 Problem and Goal

This paper's goals are to develop a parking search analysis module for GPS travel data that will be added to POSDAP and to provide a descriptive analysis of the parking search found in the Swiss GPS data for the cities Zurich and Geneva (see Section 3.1) by applying this module. The analysis is used for an ongoing project at the authors' institute and is the base for parking model estimation and validation.

Parking search traffic is a widely discussed and very political issue also in Zurich. Planungsbüro Jud (2010) shows that on Saturdays in the inner city of Zurich parking occupancy is around 97 %. Kipke (1993) indicates that searching for parking gets potentially a problem for occupancies higher than 95 %. Therefore, it is reasonable to assume that parking search can be problematic in Zurich.

The latent but very important *search starting point* is not known in GPS data. The distinction between the search and the rest of the journey is therefore not straight-forward, different from, e.g., stated preference experiments. Thus, as detailed in Section 3.2 a spatial proxy is developed, and indications for the start point are given.

The descriptive analysis provides numbers for driving times and distances in a certain area around the parking location. Furthermore, walking times and distances from parking to activity location are given. Route choice in relation to shortest path and loops are analyzed. An initial analysis of the parking type, that is on-street or garage parking, is included.

The results of this analysis will be used for calibration of parking simulations as cited in the previous section and authors' simulation described in Horni *et al.* (2012).

# 3 Method

## 3.1 GPS data and processing

For the analysis, a longitudinal GPS data set collected between 2004 and 2006 and consisting of around 32'000 person days is used. Only raw data is available, i.e., three-dimensional GPS positions with timestamps, but no accuracy information. The data set is person-based and therefore, multi-modal but unfortunately, it does not contain sociodemographic attributes. To analyse parking search relevant characteristics, the two subsets of residents of Zurich and of Geneva are used. The first is concentrated on Northeast-Switzerland and the other one on West-Switzerland (Figures 2(a) and 2(c)). Centre areas for Zurich and Geneva are defined with a diameter of 3 kilometers as shown in Figures 2(b) and 2(d). Further analysis is focused on Zurich and its twelve districts, the location of those is depicted in Figure 2 and some descriptors are summarised in Table 1. Additionally, GPS locations of public on-street parking spaces and garages are available for the city of Zurich.

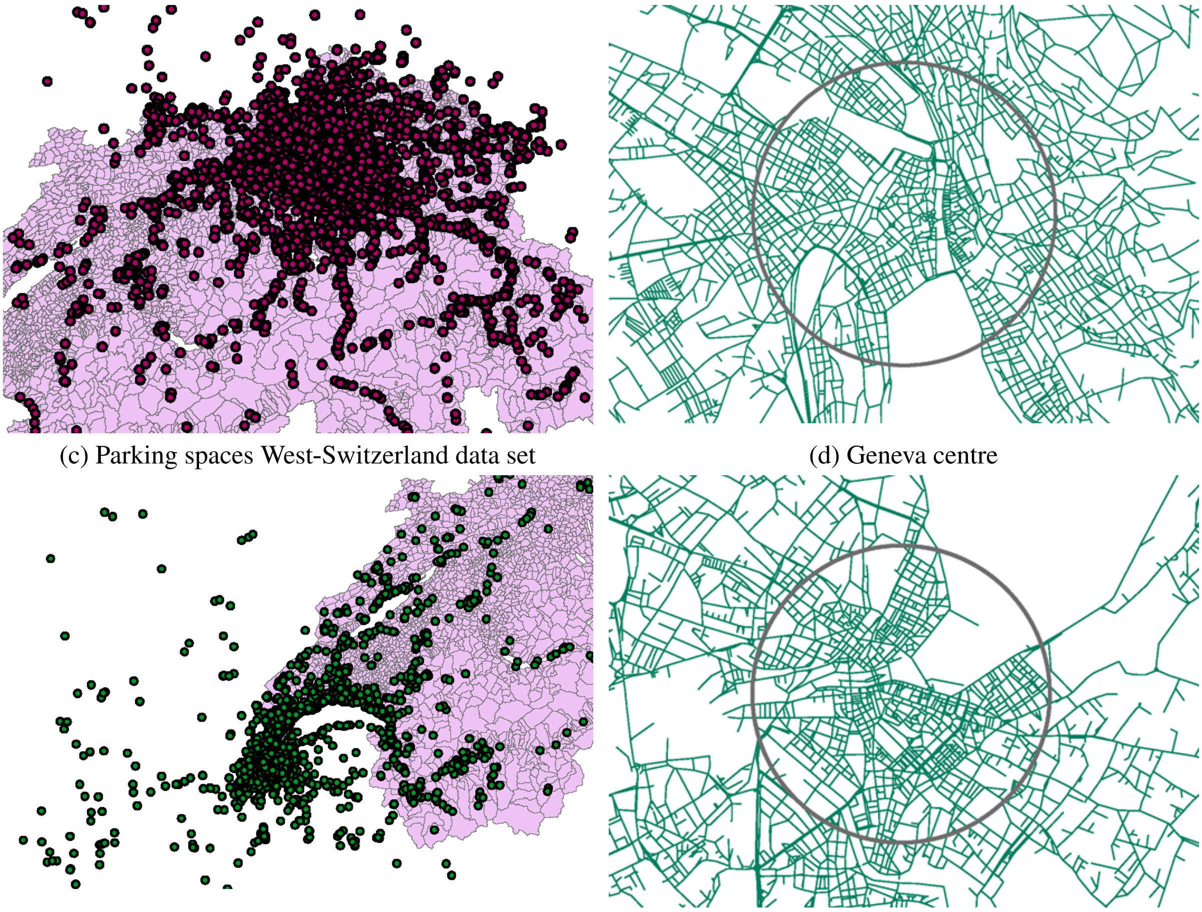
Using person-based as opposed to car-based GPS data complicates the post-processing, but it has the advantage that not only the car stages but also the subsequent walking stages or activities can be detected. For the processing the open-source POSDAP routines developed at the institute are used. In short, the GPS traces are first cleaned and smoothed to ensure reasonable speed and acceleration calculations. Later, the traces are split into stages and stop points, that is mode transfer points and activities. Then, using a fuzzy logic approach, all stages are assigned a mode.

For the parking search analysis only car stages longer than 10 minutes are considered. This decreases the probability of erratic signals being interpreted as car stages. Car stages are further categorised in:

(i) car stages followed by an activity shorter than 15 minutes and then by a stage faster than walk,
(ii) car stages followed by an activity shorter than 15 minutes and then followed by walk,
(iii) car stages followed by an activity of at least 15 minutes.

The car stages of category (i) are not considered for further analysis as signal gaps longer than 3 minutes are interpreted as stop points possibly due to tunnel usage. Another possibility is that the short activities are mode transfer points and the detected car stage might be a bus or a rail stage. For category (ii) the stop point after the walk stage is assumed to be the activity that induced car driving. This is a first approximation to be improved by trip purpose detection

Figure 1: GPS data sets and centre definition for Zurich and Geneva



(a) Parking spaces Northeast-Switzerland data set

(b) Zurich centre

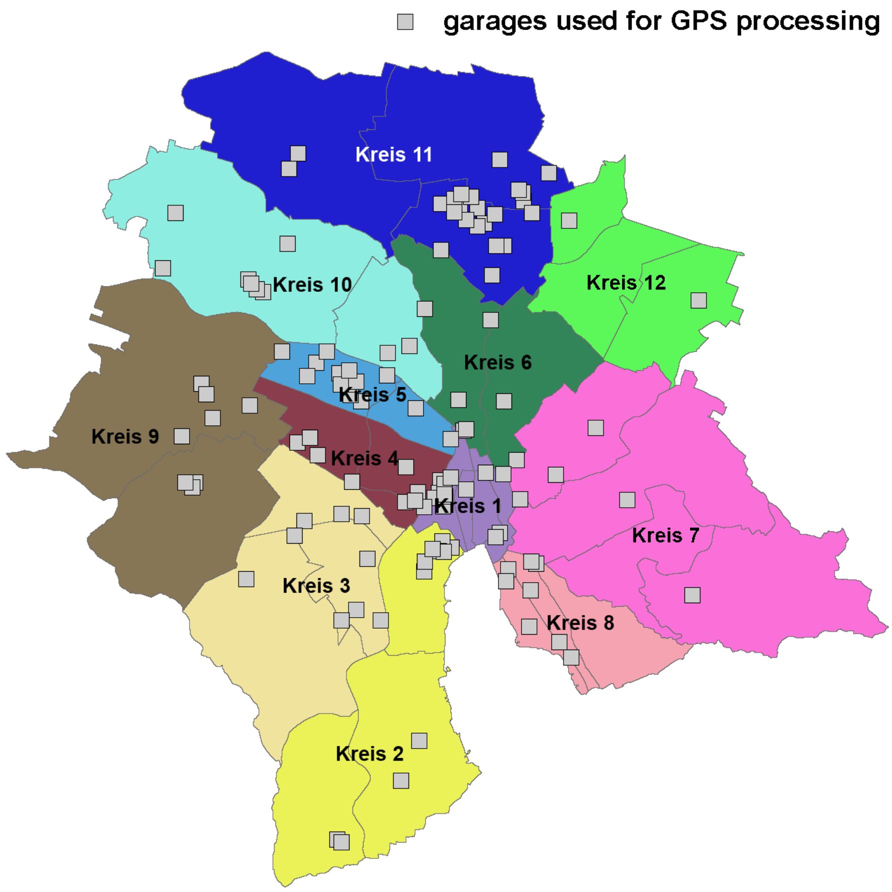
(c) Parking spaces West-Switzerland data set

(d) Geneva centre

algorithms in POSDAP. For category (iii) the immediate stop point is assumed to be the main activity. As a consequence, the walk stage to this activity is assumed to be zero meters and minutes.

The last GPS point of a detected car stage is used as an approximation of the parking space location. Using the available public parking location data, parking types are assigned to each parking space. Spaces that are nearer to a public garage location than to an on-street parking space are assigned garage, parking spaces that have a garage within 50 meters are classified as uncertain and the rest is assigned on-street parking. It is important to note that on-street parking also includes private parking. The activity location is approximated by the median of its x and y coordinates, which is mostly reasonable but does e.g. not work for long signal gaps that start and end at different locations.

Figure 2: 12 districts (Kreis) of Zurich with garages used for GPS analysis.




## 3.2 Parking search path and strategies

Several definitions for parking search start point, and consequently, the parking search path exist. Kipke (1993) suggests that the search starts as soon as the activity location is passed. This definition is problematic as this location does not have to be passed during parking search, e.g., if an activity location in a pedestrian only area or the driver finds a parking space beforehand. The second uncertainty is how well this activity location is definable e.g. eating at a friends place is easier to capture than shopping in the inner city. Birkner (1995) suggests that the search starts as soon as the first parking space is passed that would have been accepted if free. Using this definition, it is not possible to extract a start point from raw GPS data, as not only the drivers thoughts are unknown but also traffic conditions or parking occupancy, influencing the search start, are usually not available.

Unfortunately neither of these definitions can be used to extract the parking search start point and the actual search path. Therefore, we decided to use the path after entering an 800 meter

Figure 3: Path segmentation

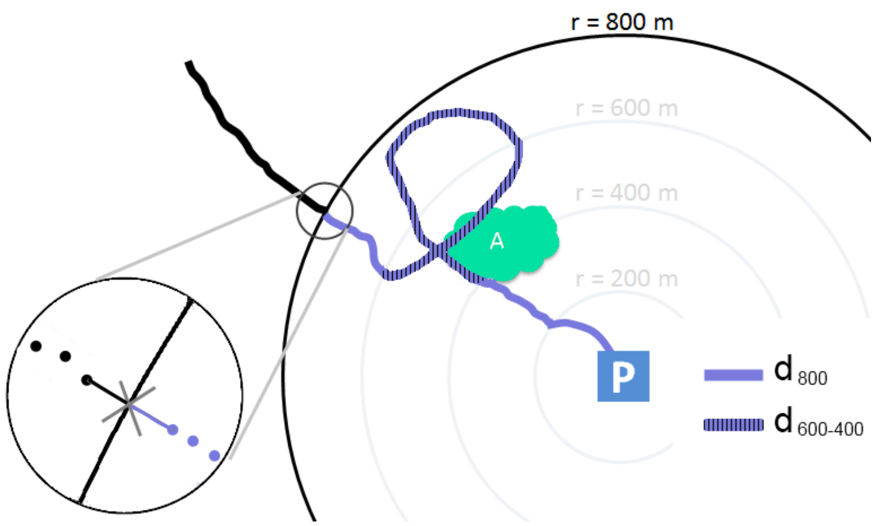
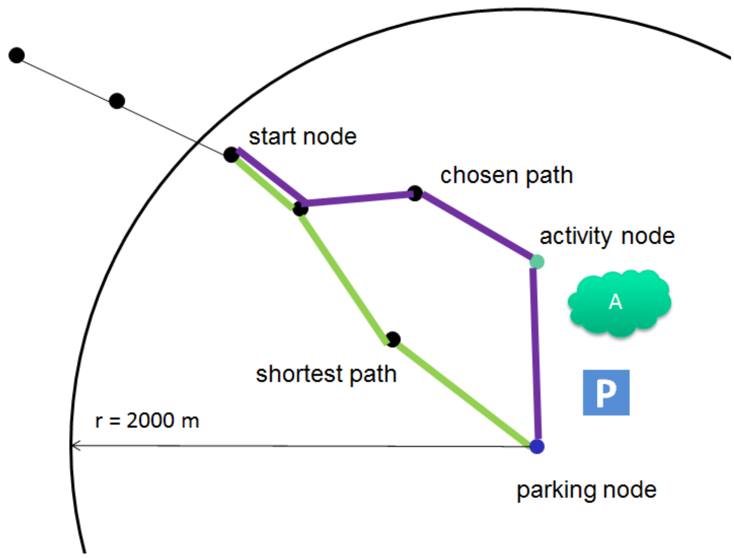



Figure 4: Chosen and shortest path




radius around the parking space as a measure to analyse parking search ($d_{800}$ in Figure 3). It is very likely that this simple measure, representing an upper bound of search effort, includes the search path. The underlying assumptions are that walking distances acceptable for the majority of car drivers in Zurich are below 600 meters (Planungsbüro Jud (1990)) and that searching for parking usually takes place between the actual found and the aspired parking space. The radius criteria is also used to split the path into segments that start when the driver enters a circle around the parking space and end when she enters the next smaller circle (e.g. $d_{600-400}$ as illustrated in Figure 3). These segments are used to analyse the progress of the search path. As distances between two successive GPS points are not negligible, the cutting point with a circle is interpolated and the distances are corrected accordingly to ensure comparability of all segments and paths.

The distance difference between the chosen and the shortest path to the parking space is, as mentioned by Birkner (1995), another possible indicator for parking search traffic but it is not the search effort itself. To calculate this difference the GPS points of the car stage are first map-matched (Schüssler and Axhausen (2009a)). The last node of the resulting path is defined to be the parking node. The start node is defined to be the first node within 2 kilometers around the parking node (see Figure 4). This start and parking node are then used for shortest path calculations using Dijkstra's algorithm with distance as cost. Using the difference between the paths of the complete journey would lead to differences due to the chosen route into the city. But we are only interested in the last part of the journey that could be influenced by parking choice.

Having extracted the chosen path it is used to get an indication for the underlying search strategy. (Polak and Axhausen, 1990) identified seven strategies that are briefly described here:

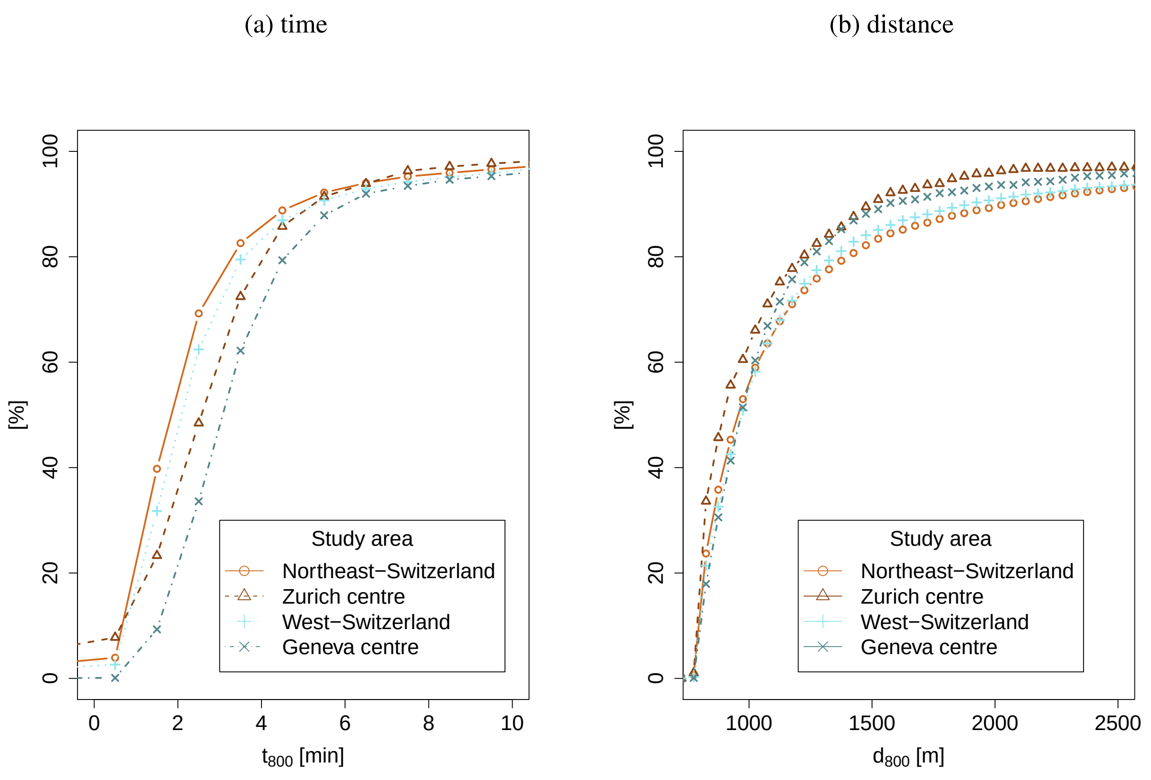
(i) Drivers drive directly to an almost guaranteed 'inside tip' parking place that is not officially for them (e.g. customer parking spaces).
(ii) Drivers know a fixed number of opportunities which almost always lead to no search time (e.g. garage, facilities around the core) and drivers are willing to accept long walking distances.
(iii) Drivers drive in direction of a garage but use on-street facilities if available.
(iv) Drivers have a fixed sequence of on-street and cheaper off-street opportunities and accept long walks.
(v) Drivers adapt search according to trip purpose and duration, illegal parking is an option. Search time might be long.
(vi) Drivers circle around their destination and long searches are accepted to ensure short walks.
(vii) Drivers accept illegal parking for short stays.

Strategies (i) and (vii) are undetectable in GPS data as illegal or customer parking spaces are most likely near legal public parking spaces and the resulting short search times can not be assigned to these strategies, as short searches also result from private parkers or parking during unproblematic times where no search strategy is needed. Only strategies (ii) and (iii) use garages, information that was extracted from GPS travel and parking location data. Strategy (iii) can also lead to on-street parking and can therefore easily be misinterpreted - GPS data of several weeks might help identify such drivers if parking spaces are often near or in garages. Strategies (iv), (v) and (vi) are all on-street parkers with possibly long search times and are therefore hard to distinguish. Strategy (iv) might be extracted if several weeks of data is available as the drive patterns stay the same. Driving in circles (vi), is detected by inspecting the map-matched chosen path for network nodes traveled several times. GPS data can consequently hint at strategies (ii), (ii) and (vi) which is investigated in the next section.

# 4 Findings

Results are provided for Northeast- and West-Switzerland. As Geneva is more densely populated than Zurich the hypothesis is that searches are longer in Geneva. This was confirmed for search times but not for search distances as can be seen in Figure 5. Search times were also higher in the centres, interestingly this does not hold for distances. This is influenced by lower speeds in the centres, but maybe also points to different search strategies.

Figure 5: Time and distance driven within a radius of 800 meters around parking space for Geneva and Zurich.




For the remainder of this chapter analysis is focused on car stages ending in the city of Zurich. Two districts with different characteristics are highlighted. Kreis 1, the historic inner city, that stretches from the lake to the main station including shopping streets, commercial and very expensive residential buildings. It has many more employees than residents and the share of parking spaces is lowest with 0.13 spaces per resident and employee (Table 1). Kreis 9 on the other hand has the highest share of parking spaces (0.45). It is much larger and it is a commercial but also residential district.

In total, 4086 car stages longer than 10 minutes are detected. Approximately 20 % of those are filtered as they are not followed by a walk or a long activity as shown in Figure 6. Still for each district at least 130 cases are left after filtering. The figure also shows that the share of car stages followed by a long activity, that is where a parking spaces was found immediately, is highest in Kreis 9 and lowest in Kreis 1 which corresponds to the ratio of parking space to residents and employees.

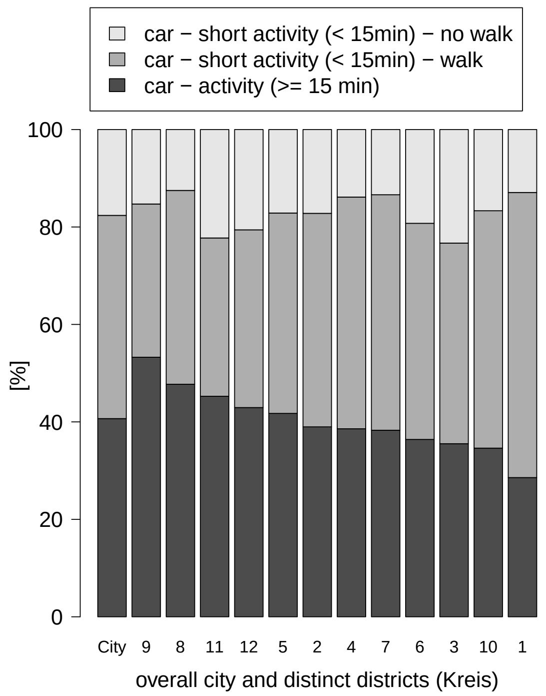
Table 1: Zurich city data by district (Stadt Zürich Präsidialdepartement, Statistik Stadt Zürich (2011))

| **District** (Kreis) | **Residents** | **Area** (ha) | **Parking spaces** | $\frac{\textbf{Parking}}{\textbf{(res. + empl.)}}$ | **car cases** |
|---|---|---|---|---|---|
| **1** | **5563** | **180** | 9087 | **0.13** | **294** |
| 2 | 29878 | 1106 | 24931 | 0.39 | 372 |
| 3 | 46699 | 865 | 25805 | 0.32 | 442 |
| 4 | 27429 | 280 | 18005 | 0.31 | 368 |
| 5 | 12764 | 209 | 16351 | 0.34 | 321 |
| 6 | 31464 | 511 | 16838 | 0.35 | 239 |
| 7 | 35447 | 1502 | 24833 | 0.42 | 269 |
| 8 | 15518 | 481 | 14899 | 0.39 | 176 |
| **9** | **48494** | **1207** | **39504** | **0.45** | **458** |
| 10 | 36879 | 907 | 20705 | 0.41 | 312 |
| 11 | 65796 | 1343 | 42666 | 0.40 | 665 |
| 12 | 29537 | 597 | 13374 | 0.39 | 170 |
| **City** | **385468** | **9189** | **266998** | **0.36** | **4086** |

## 4.1 Driving distances and times

For the applied analysis method, the minimum driving distance is of course 800 meters. The additional driving distance is influenced by the network, that is by the shortest possible path, considering one way streets, speed limits but also by the drivers knowledge of the city. The driving times are additionally influenced by traffic conditions. Driving times in the inner city (Kreis 1) are highest but driving distances are shorter (Figure 7), as this area is more congested and speeds are lower. In general driving times are less than 4 minutes for 80 % of cases in the overall city; distances driven range from 1100 to 1400 meters for 80 % of cases, which indicates that parking search substantially varies for districts. Possible remaining processing errors such as misinterpretation of bus or rail stages wrongly identified as cars do not include search paths

Figure 6: Categorisation of detected car stages.




and thus lower the distance and time estimates. Consequently the share of low estimates is too high and has to be corrected if used as upper limits in parking models.

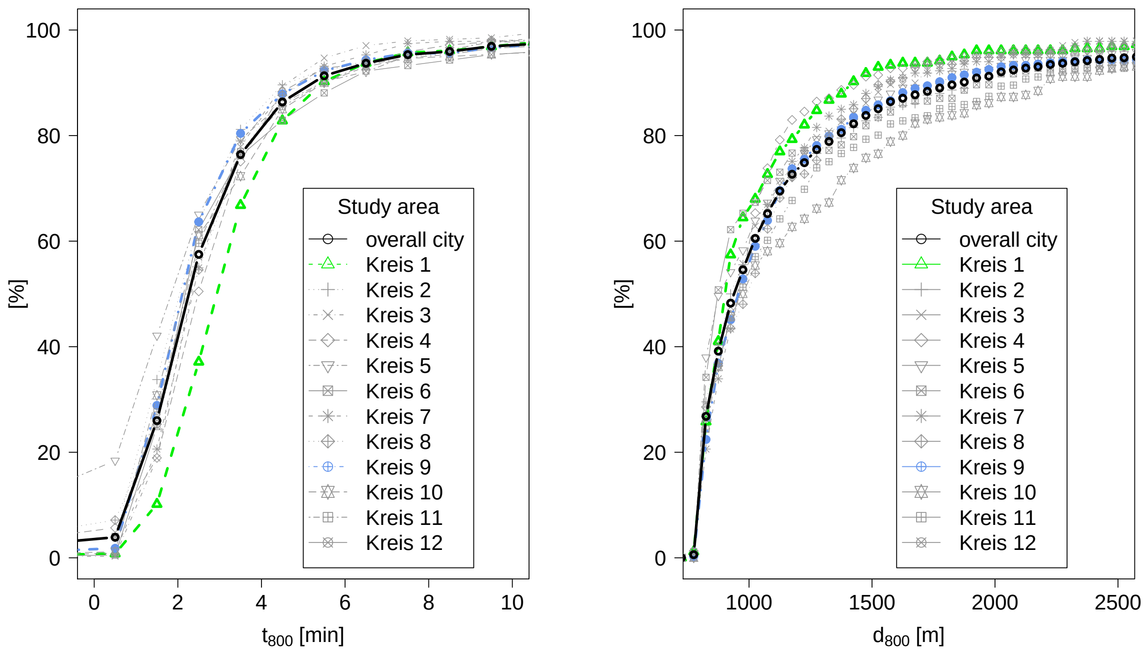
In the city, the distance difference of the chosen and shortest path is below 500 meters for more than 80 % of cases (Figure 8). As expected, for the complete data set the distance differences are lower. It is mostly due to the fact that over 60 % of stages in the Northeast-Switzerland data set were shortest paths. In the city, this share is considerably lower but still around 50 %.

## 4.2 Walking times and distances

Times and distances walked after parking are depicted in Figure 9 for all districts and the overall city. Walking trips are potentially underestimated as they are ended by stop points of 3 minutes which might be a short stop on the way to the actually planned main activity. In Kreis 9 over 65 % of car stages end at the activity. For another 25 % of observations the subsequent walk is less than 5 minutes or less than 400 meters respectively. In Kreis 1, considerably less but still 40 % park at the activity location and for another 40 % of observations walk is less than 400 meters. The difference of the 90th percentile is around 2 minutes showing that parking success

Figure 7: Time and distance driven after entering an 800 m radius around parking space.

(a) time (b) distance



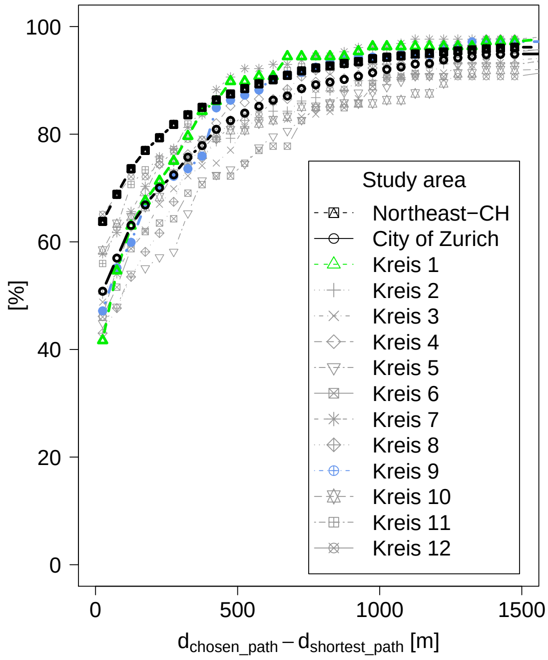

substantially depends on location.

## 4.3 Speed distribution

The distribution of the average speeds in path segments (illustrated in Figure 3) are depicted in Figure 10 for Kreis 1 and 9, which are chosen as previously. Kreis 1 is interesting as it is the district in which parking searches are longest and Kreis 9 has a similar speed distribution as the city overall. As expected speeds in Kreis 1 are generally lower than in the overall city and Kreis 9. In both districts, the average speed on the last 200 meters are considerably lower than 1000 meters away from parking space. For all districts it was found that aggregated speeds strongly decrease when approaching the parking space. The differences between the segment speeds are very small for Kreis 9 but for Kreis 1 they are more pronounced.

This is probably due to two influences: first, traffic slows down when approaching city centre. But as parking spaces are spread all over Kreis 1 (Figure 11(c)), speeds of the same path segment are not speeds of the same area, the second possible influence is therefore drivers slowing down because they start searching. Consequently speed distributions can point to the start of parking

Figure 8: Difference chosen and shortest path on the last 2 km to the parking space.



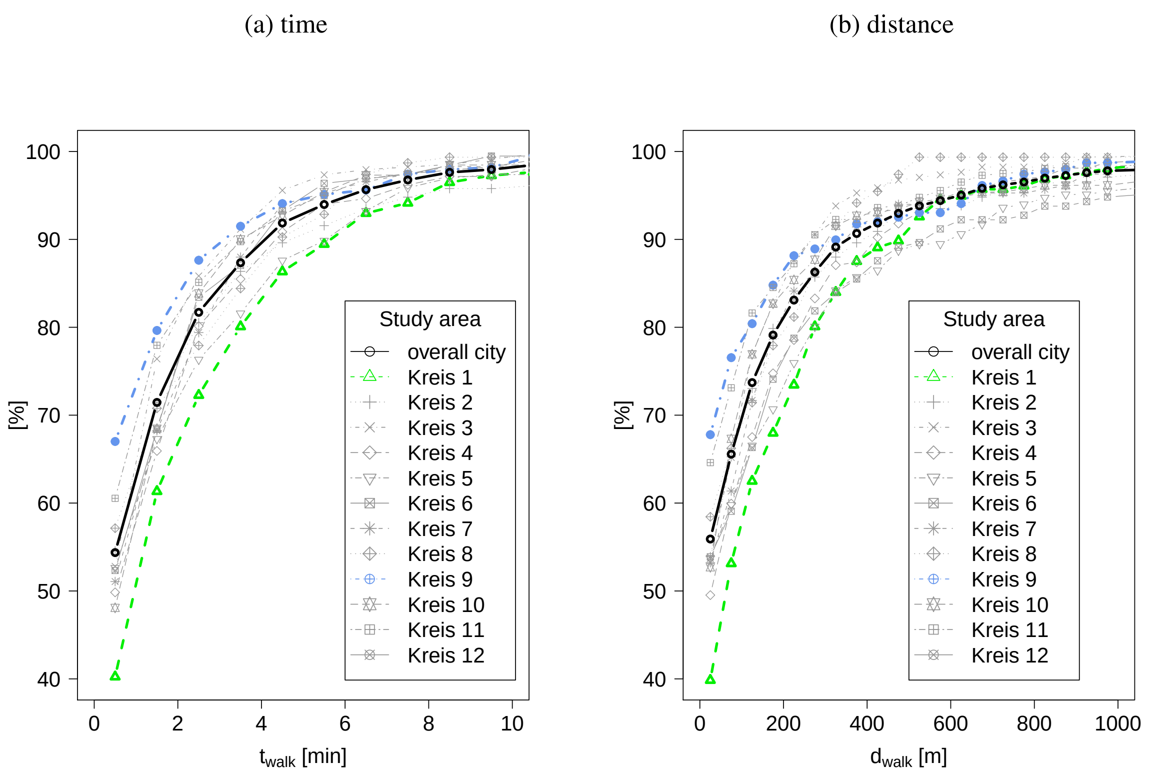

search, e.g., parking search starts earlier in Kreis 1 than 9.

## 4.4 Search path

To identify drivers circling while searching as described in the strategy (vi) of Section 3.2, loops of the extracted chosen path are counted. Less than 10 % of the paths contain one loop. And only very few paths, that is less than 1 %, contain more than one loop. This indicates that circling is not necessary or favoured by drivers. The highest share of potential circling drivers are found in Kreis 5 a former industrial district, least in Kreis 9, this maybe due to more private parkers there.

Search strategies considering public garage parking (ii and iii) are used in 5 - 15 % of cases (Figure 11). The public garages used for classification are shown in Figure 2. All districts have garages still no surveyee parked in a garage in Kreis 3, a residential district. This this might be because garages there are public but mostly for very specific trip purposes, potentially not performed by the respondents in the survey period. In the entire city for 98 persons more than 3 parking activities are identified. Of those 27 used garages and on-street parking and and only 1

Figure 9: Time and distance walked for all districts (Kreis) of Zurich.




person used garages in all cases.

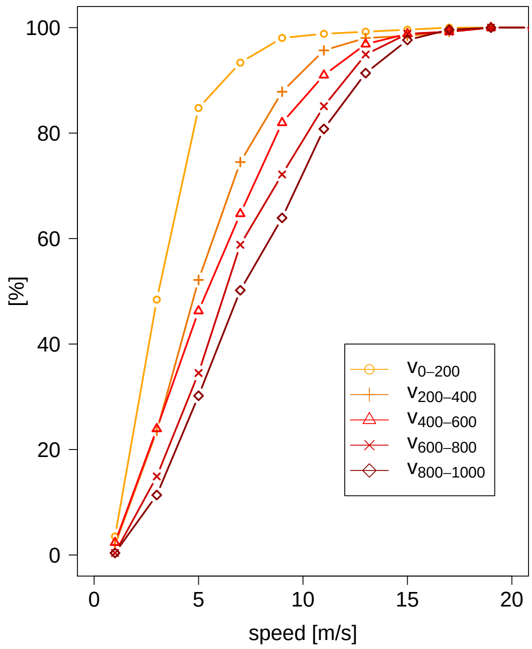
Interestingly, garage and on-street parking strategies lead to very similar distributions of walking distances (Figure 12).

## 4.5 Dynamics

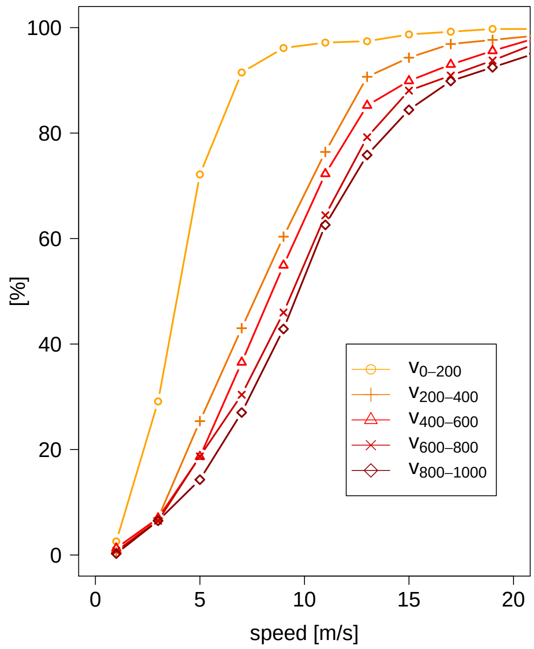
As trip load curves commonly show clear peaks, assuming peaks in parking search effort is natural. However, Figures 14(a) and 14(b) show that there are no pronounced peak days or hours for parking search traffic in Zurich. Peaks might level out as the analysis is performed on the whole city, which is necessary here due to small sample size. Furthermore, parking assumedly has to be seen as a cumulative phenomenon smoothing the peaks in demand. In other words, parking search is not necessarily easier for trip off-peak times than for trip peak hours. Having no peaks can also mean, that either parking demand is very low or that it is always in saturation range.

Figure 10: Speed distribution for path segments and parking spaces Kreis 1

(a) Kreis 1




(b) Kreis 9




(c) Distribution of parking spaces in Kreis 1.

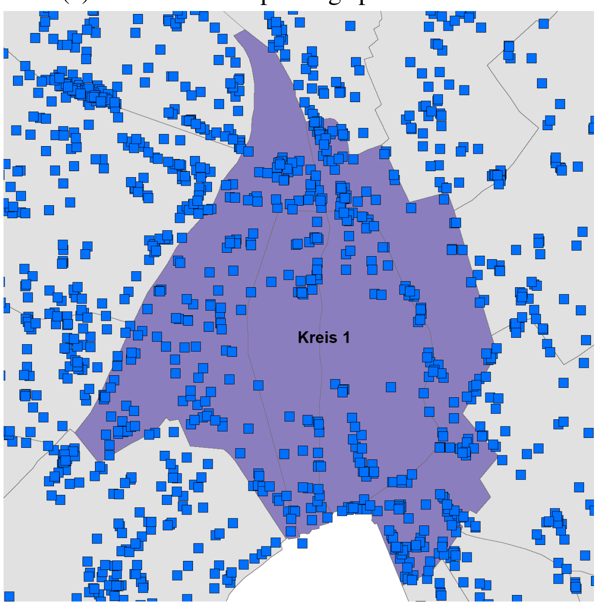


Figure 11: Parking type - on-street vs. garage.

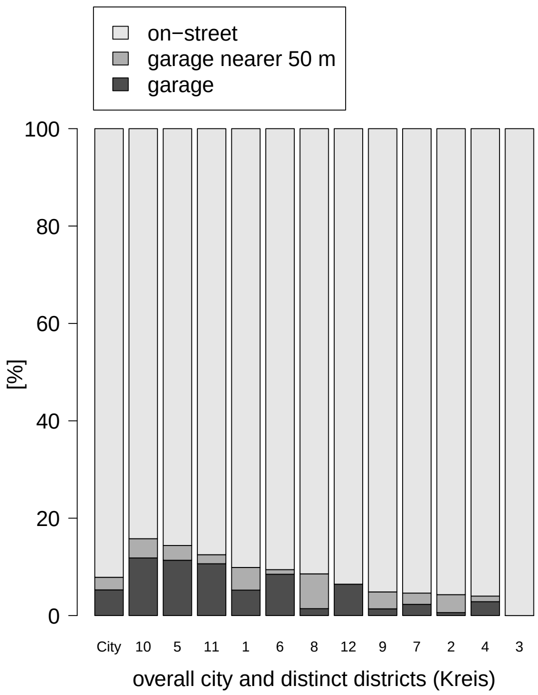


Figure 12: Walking distances for garage and on-street parking.

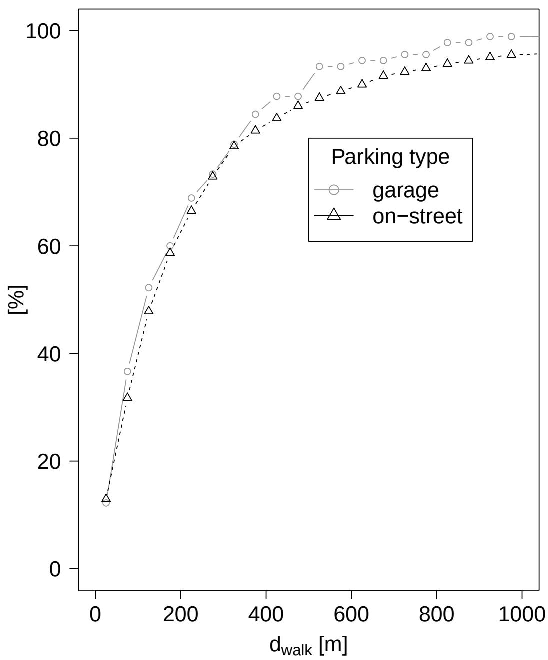
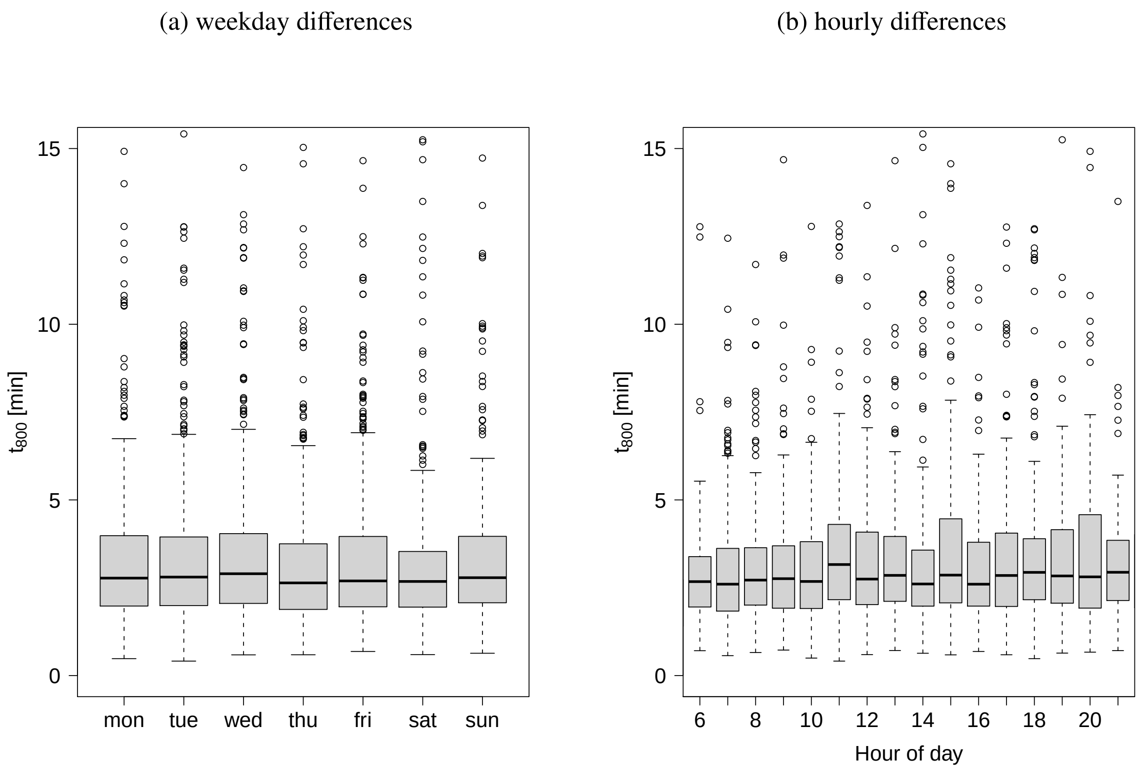


Figure 13: Driving times within 800 m of parking for Zurich city.



# 5 Conclusion & Outlook

Quantification of parking search effort is difficult and results found are controversial as a large range of values is found for different studies and locations (e.g., Shoup (2005)). Clearly, situation strongly differs from city to city. However, differences are also due to diverging definitions, latency of parking search and bias in reporting parking search effort. Usually, parking search is regarded as important. However, parking search for Zurich seems to be undramatic based on indicators computed in this study. The time driven with an 800 meters radius around parking space is less than 4 minutes for 80 % of cases in the overall city; distances driven range from 1100 to 1400 meters for 80 % of cases, which indicates that parking search substantially varies by districts. For a plausibility check, number of parking spaces per resident and employee per district (overall city: 0.36) and share of parking spaces on private ground (overall city: 81 %) have been computed (see Table 1). Both numbers are relatively high inducing low parking search being inline with the computed results.

However, this is a first explorative analysis with the main goal to develop and improve parking search extraction methods. The data set used here does only contain raw data, i.e., no socio-demographics—important for model estimation—and no accuracy and accelerometer data—important for high-quality processing—are available. Results have to be interpreted as indications. Distance and driving times are potentially underestimated due to wrongly detected public transport stages. Walk times are also potentially underestimated by misinterpretation of the following main activity. More reliable results are expected using a new GPS data set currently being collected at the authors' institute. That study aims to survey 200 participants living in and around Zurich. Participants carry a person-based GPS device for 7 days and they correct the automatically produced travel-diary using a web-based prompted recall interface. Additionally, they fill out an online questionnaire consisting of socio-demographic attributes as well as psychometric scales concerning environmentalism, variety seeking and risk propensity.

The findings concerning parking choice can be compared to stated preference studies conducted in Zurich. Results can be used to calibrate parking search models e.g., in the agent-based transport simulation MATSim or in the authors' simulation (Horni *et al.,* 2012). Furthermore, the data can be used to estimate parameters of a discrete choice model for parking location choice given the full set of information currently collected at authors' institute.

Future calibration and improvement of the processing steps preceding parking detection is crucial for accurate identification of parking and subsequent activity location. Most important but also challenging is the planned implementation of *trip purpose detection*, as it can be assumed that parking behavior heavily depends on type of activity. These routines should also reveal pseudoor intermediate activities (e.g., window shopping) while walking to the actually planned main activity. It can be assumed that in questionnaires only this main activity is reported while in GPS data intermediate activities are recognized, leading to a biased estimation of walk distances (underestimation).

As private parking is usually associated with only little or no search, an important future task is to distinguish the analysis between private and public parking.

Loop analysis is in the first instance based on network node counting. As this is highly dependent on network resolution, analysis should in the future be refined to areas (instead of using single network nodes). In other words, loops are counted if a certain area is crossed multiple times.

To reveal if higher travel times (and potentially detours with respect to free-flow minimal path) are due to search or due to traffic conditions a time-dependent analysis for persons without activity or parking in the respective area should be performed, in particular for inner city areas, and compared with the speed distributions given in Section 4.3.

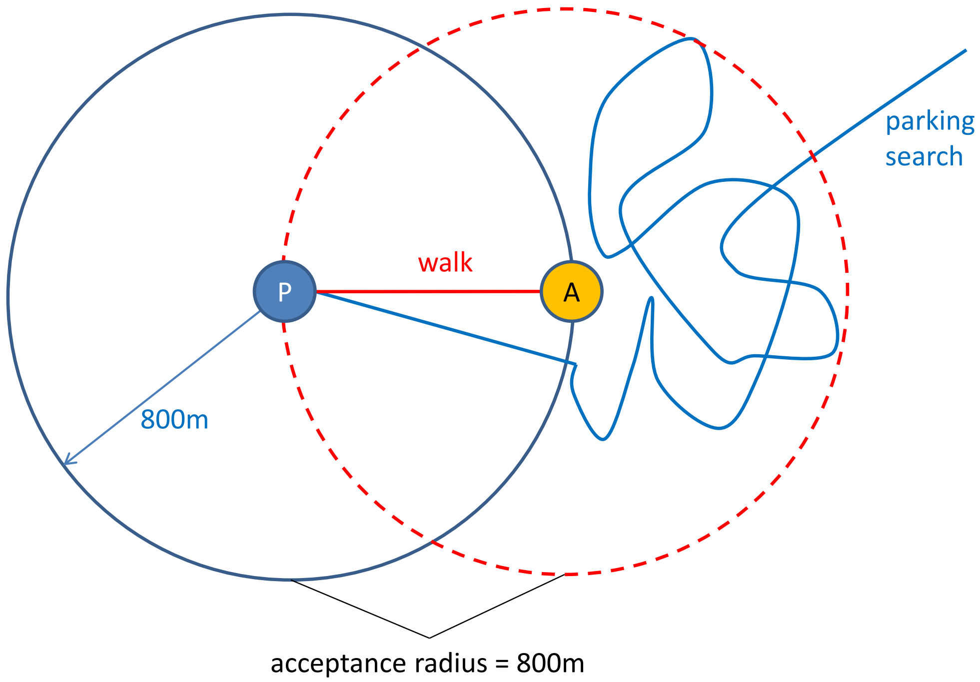
There is a discrepancy between average search effort found in GPS data and subjective parking effort estimation reported in personal communication, where higher search times are expected. Thus, an additional analysis should focus on the high efforts including outliers.

Considering a circle around parking location, as done in this work, but also around the activity, harbors the danger of missing part of the parking search in situations where a long walk is followed (see Figure 14). Combining analysis of a region around both the parking location and the activity should be tested.

Entering a tunnel may be misinterpreted as parking although speed analysis for the last 200 meters being lower than the rest of the journey indicates that most cases end actually in parking and are not misinterpreted tunnel rides. However, these cases should be decreased in the future as currently work is done on the POSDAP routines to distinguish between signal gaps where movement takes place and gaps that are actual activities. Further, improvements of mode identification using public transport networks are being developed (Rieser-Schüssler *et al.* (2012)).

Indications for the latent but very important *actual search starting point* are revealed. They can be compared in future to the results of an ongoing study where GPS data is only collected as soon as respondents recognize that they start searching for parking.

Figure 14: Circle around parking or activity location: parking search right to activity location is missed in this case.



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