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PUBLIC TRANSIT SERVICE-OPPORTUNITIES IN COMMUTER-BELT MUNICIPALITIES – A SYSTEMIC ANALYSIS OF TWO DISTRICTS IN THE VIENNA REGION

ABSTRACT

Public transport in the transition zone from cities to rural areas is increasingly becoming a focus from the financial and public service provision perspective. The (perceived) supply differences of rural and remote areas are on the agenda of policy discourse. Our survey studies the public transport supply of two districts and their municipalities in the region of Vienna, Austria, by using the parameters of service-opportunities, municipal population, acreage of settlement units and potential demand. Annual service-opportunities is a parameter recorded by the public transport authority of the Vienna region for every single station under its zone of influence. These parameters are analyzed to conclude that service-opportunities pose a viable entity for systematic public transport analysis and differences in supply of these two districts are in contrast to expectations. Finally, we address the need for future development of service-opportunities based analyses.

KEY WORDS

public transport supply; rural district; station density; service-opportunities; potential demand;

1. INTRODUCTION

Whereas most research focuses on urban public transport (PT), the changes in population structure of recent decades have led to new challenges and ideas of flexibilisation for PT in rural areas. The constant migratory flow from villages and rural towns to urban centres and their peri-urban fringes has left many regions with very diverging internal population developments and has put a pressure on the organisation and financing of PT for regions of this kind [1, 2]. Such strongly differing structural conditions with distinct gradients of PT service within a small distance can be found especially in transition zones from urban commuter belts to rural areas. Very often the perceived inequality between these areas governs the public demand for improvement or serves as a justification for service underutilization. Such conditions call for a quickly adaptable systemic survey of provided services. The analysis of service-opportunities serves this purpose well. The knowledge of PT supply on a regional level is of importance not only from a regional policy standpoint to balance regional inequalities but it also provides benchmarks for the improvement of services to cover the existing demand better, or even stimulate new demand.

The quality of PT performance can be appraised on different levels and from different perspectives. Such evaluations range from individual lines and corridors [3], via the behaviour of multi-line systems up to the transnational comparison of cities and their PT characteristics [4]. The efficiency of public transport as a function of governance and financing structures, e.g. in the form of PT organizing bodies and fare systems has been analysed by some authors [5, 6, 7] as well as the efficiency of PT companies [8]. As PT systems incorporate complexity, an analysis of systems instead of simple lines calls for all-encompassing quality parameters like "Transit Quality of Service" or "Level of Service" [9]. Important partial aspects of PT systems like the network design impact on service regularity

[10], timetables [11, 12], the connectivity of PT services [13], line routing and operational efficiency [14, 15] have been analysed before. Often, analysis is also based on the production perspective of PT, using input parameters like labour force, capital, vehicle and seat kilometres [3, 8, 16]. Furthermore, from an individual perspective, the rider's valuation of services [17] and amenities at PT stations [18] have been subject of analysis as well as overall efficiency of PT rolling stock [19].

This paper is based on a recently conducted analysis of PT supply for two administrative districts close to Austria's capital Vienna: Baden (BN) and Gänserndorf (GF). These two districts have inherited different properties in terms of location, geographical extent, size and number of municipalities. But both districts are partly located in or touch the peri-urban fringe of Vienna. Both studies are aimed (a) at identifying the service quality on a systemic level and (b) at comparing the features of both districts. For this a systemic macro-scale PT supply parameter approach was adopted by utilizing the metric service-opportunity (SO) for every PT station in the region and aggregate parameters like number of PT stations in combination with population and size of settlement units on a municipal scale.

The next section focuses on data and methods used for the analysis and the results thereof are displayed in section three. Finally in the last section these results are discussed and conclusions for further systemic PT analysis are drawn.

2. MATERIALS AND METHODS

The input data for the analysis were provided by Verkehrsverbund Ostregion (VOR), the organising and financing body of PT in the Vienna region: service-opportunities (in German: Servicefahrten) per individual station, transport mode and day of operation for every station within the area of both districts. Service-opportunities are defined by VOR as the number of stops of PT modes per station in a given period of time according to the timetable. The period of time under consideration is either one year in total – the regular validity of the timetable – or separated by days of operation: Monday through Friday during school time or during school holidays, Saturdays, Sundays and general holidays. *Figure 1* illustrates the metric of service-opportunities by means of three symbolic bus lines. For example, every bus line usually has stations with scheduled stops and stations that may be left out due to express service, deviant routing of singular runs or lack of passenger's needs to board or alight. So the bus run does not actually stop at that station. In the example of *Figure 1* three lines cross a municipality with one bus running in every direction and having a potential scheduled stop at every station. These stops may not necessarily be realized, as no passengers would show up to board or no passengers would request a stop to alight. At each station each line produces 2 service-opportunities due to their 2 buses. At stations where n lines meet 2 times n service-opportunities arise. Summing up all the municipal stations produces the service-opportunities of the municipality, in our case 18. The total number of such scheduled potential stops of runs at stations denotes service-opportunities per station. This metric is irrespective of a bus actually halting there or not, as for example is also the case for stops on demand. The service-opportunity data fielded into single stations with municipality code, days of operation and actual means of transport, so in the analysis we were able to utilize dedicated sub-sums of the dataset. VOR data include SO for all PT modes, rail and bus.

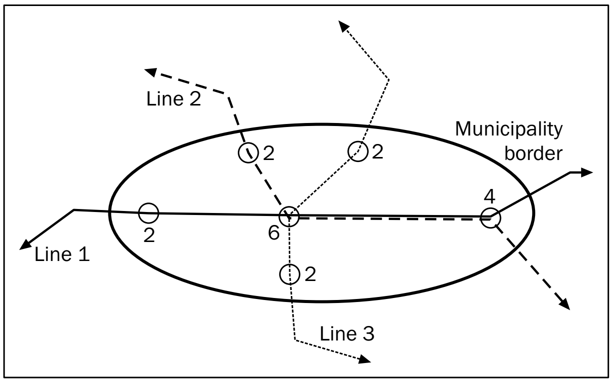

Figure 1 - The service-opportunity concept explained in an exemplary scheme

The Austrian federal statistics office "Statistik Austria" measures different surface parameters of municipalities: total area, permanent residence area (PRA) and the area of settlement units (SU), which conforms to the population cluster in Regulation (EC) No. 1201/2009. While PRA includes farmland and other not directly built-up areas, SU accounts only for patches of continuously built-up land with at least 200 inhabitants. For eight out of seventy-four municipalities the SU measure was not available from "Statistik Austria", because they did not meet the threshold values. As these municipalities ought to be included in the analysis, the SU size A'_{SU} was approximated by using the average area per inhabitant in SU for districts. Factors φ and ψ denote the proportion of population within and outside the district's SUs respectively. Population density δ is derived for SU and in permanent residence areas (PRA) for total municipal population P_{MUN}. A denotes area and index $DIST$ stands for district (1).

$$A'_{SU} = P_{MUN}\left(\frac{\varphi_{SU,DIST}}{\delta_{SU}} + \frac{\psi_{SU,DIST}}{\delta_{PRA}}\right) \tag{1}$$

with

$$\varphi_{SU} = \frac{P_{SU}}{P_{DIST}};\ \psi_{SU} = \frac{P_{1-SU}}{P_{DIST}};\ \delta_{SU} = \frac{P_{SU}}{A_{SU}};\ \delta_{PRA} = \frac{P_{MUN}}{A_{PRA}} \quad (2)$$

In the final step of analysis both districts are combined. As actual passenger demand figures were not available to check the service-opportunities we introduced a daily "potential demand (*PotDem*)" function for each municipality. *PotDem* is the sum of two functions: one considering relations between the different municipalities and Vienna and the other considering the relations between different municipalities and the capital of each district – Baden or Gänserndorf (3).

$$PotDem_X = PotDem_V + PotDem_{DC} \quad (3)$$

While $PotDem_X$ denotes the potential demand of municipality X, $PotDem_V$ specifies the potential demand in relation to Vienna and $PotDem_{DC}$ the potential demand in relation to the district capital (Baden or Gänserndorf). *PotDem* is calculated for the municipalities according to a typical gravitational model that explains trip distribution between Vienna and the district capitals with their regional surroundings (4).

$$PotDem = \mu \cdot \frac{P_i^{\alpha} \cdot P_j^{\beta}}{d_{ij}^{\gamma}};\ PotDem_V = \mu \cdot \frac{P_X^{\alpha} \cdot P_V^{\beta}}{d_{X,V}^{\gamma}};$$

$$PotDem_{DC} = \mu \cdot \frac{P_X^{\alpha} \cdot P_{DC}^{\beta}}{d_{X,DC}^{\gamma}} \quad (4)$$

with P being the population of a municipality, d_{ij} being the as-the-crow-flies distance between municipalities i and j. Parameters α, β and γ define the gravitational model and μ was chosen as a position variable to produce coefficients within reasonable values, i.e. to avoid obtaining too small or too big numbers that may be difficult to use. We set the values to $\mu = 0.01$, $\alpha = 0.6$, $\beta = 0.8$ and $\gamma = 1.5$ in accordance with the experience obtained with the surveys of Valencia and Alicante strategic urban mobility plans [20, 21]. *PotDem* is then correlated with SO and commuters (*Comm*) and the fits are examined using the Statgraphics software. *Comm* are daily work commuters departing from the municipality to work in another one. Tadat from micro census 2009 have been provided by "Statistik Austria".

3. ANALYSIS RESULTS

Baden district's (BN) total population amounts to 138,000 inhabitants, whereas Gänserndorf (GF) has 96,000, see *Table 1*. BN's population is distributed among 30 municipalities (population min. 822, max. 25,136), whereas GF district's smaller population is scattered over a larger number (44) of smaller municipalities (population min. 91, max. 10,457). *Table 1* shows extremes of parameter values for both districts. From the total number of stations via SO per district to SO per station, the span of parameters is derived from both datasets. GF values suggest a more rural situation than BN district data does. To-

Table 1 - Extreme parameters of both case study districts; Names in brackets denote the name of the station or municipality.

District	BN	GF
Total population per district	138,000	96,000
Min. population of municipality	822 (Furth/Triesting)	91 (Großhofen)
Max. population of municipality	25,136 (Baden)	10,457 (Gänserndorf)
Total stations in district	406	391
Min. stations per municipality	3 (Schönau/Triesting)	1 (Parbasdf., Andlersdf., Großhofen)
Max. stations per municipality	81 (Baden)	42 (Gänserndorf)
Total SO in district per year	4,919,121	3,084,033
Min. SO per station and year	184 (six stations[a])	191 (three stations[b])
Max. SO per station and year	218,698 (Baden Bahnhof)	136,151 (Großenzersdorf Busbahnhof)
Min. total SO per municipality and year	8,715 (Furth/Triesting)	1,781 (Parbasdorf)
Max. total SO per municipality and year	1,903,151 (Baden)	606,996 (Groß-Enzersdorf)

a... Baden Erzherzogin-Isabelle-Str, Klausen-Leopoldsdorf Volksschule, Sooß Bezirksstraße, Enzesfeld Volksschule, Heiligenkreuz Volksschule, Ödlitz Ortsgrenze St Veit
b... Gänserndorf Süd Eschenweg, Gänserndorf Süd Habichtweg, Markgrafneusiedl Raika
Data source: Verkehrsverbund Ostregion – VOR

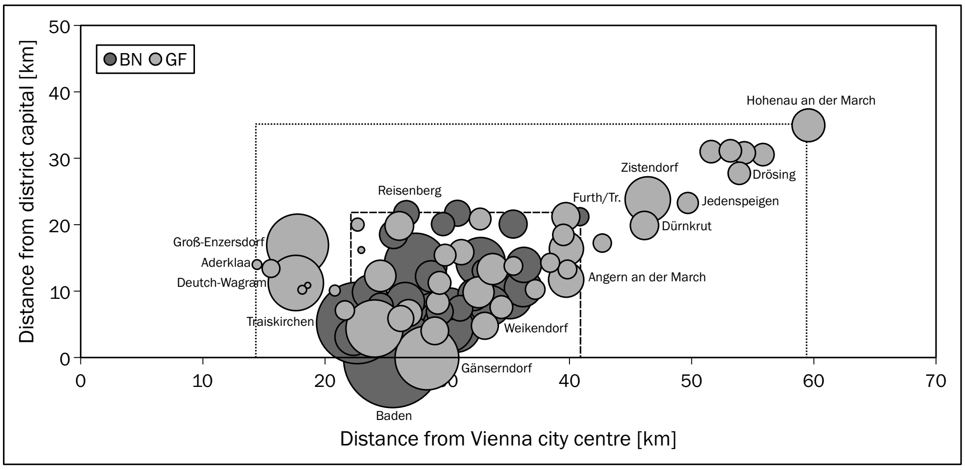

Figure 2 - Scatter plot of geographical structure of municipalities in districts Baden (BN, dashed dark grey) and Gänserndorf (GF, dotted light grey) with circle area proportional to population. The diagram axes show as-the-crow-flies distances from Vienna city centre (x-axis) and from the district capital (y-axis) respectively.

tal SO rates at 1.6 to 1 which is very similar to the rate of population being 1.4 to 1. On the other hand for maximum municipal SOs, Baden's value is 3.14 times higher than that of Groß Enzersdorf, where population rates behave like 2.6 to 1 in favour of Baden. *Figure 2* illustrates the different inhabitant distributions by using the as-the-crow-flies distance from Vienna city centre and from the district capitals Baden and Gänserndorf and the circle size is proportional to population. The rectangles show how much the district is spread out. Baden district shows a more compact structure, as the distances to Vienna range from 22.2 (Pfaffstätten) to 40.8 (Furth/Triesting) and the furthermost municipality is placed 21.8 km (Reisenberg) from Baden. In GF the structure is more spread out. Not only are peripheral municipalities located up to 34.9 km (Hohenau) away from Gänserndorf municipality, but also the distances to Vienna vary considerably; 14.4 km (Aderklaa) to 59.5 km (Hohenau).

When the service-opportunities sums of both districts related to population size for different days of operation are compared, a difference in favour of BN district is visible on every day of operation. Also, for both districts a consecutive reduction in service quantity is easily identifiable (*Figure 3*).

The linear approximation of population density in SU with station density in SU of GF district shows a slightly better level of service quality than BN district (see *Figure 4*). In both cases the correlation coefficients show a remarkably well fit with R^2 of 0.94 and 0.69, respectively.

When plotting the relative number of inhabitants per station over population on a municipal basis (*Figure 5*), a convergence towards the average appears with the increment of population size for both districts. For populations up to 5,000 inhabitants the divergence of station population values shows a factor of 7, ranging from 100 to 700. GF district municipalities appear to be spread distinctively be-

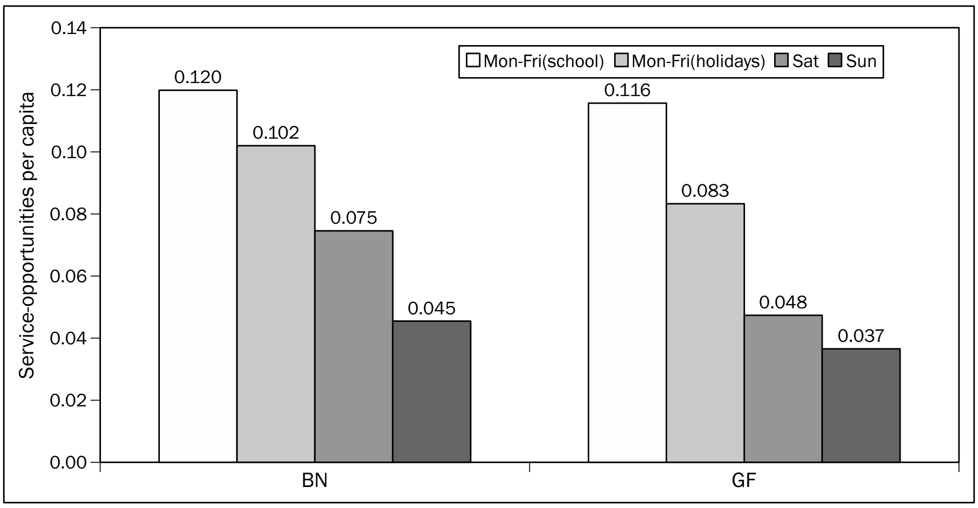

Figure 3 - Total sum of service-opportunities (SO) per capita for BN and GF districts on Monday-Friday (school), Monday-Friday (school holidays), Saturdays and Sundays

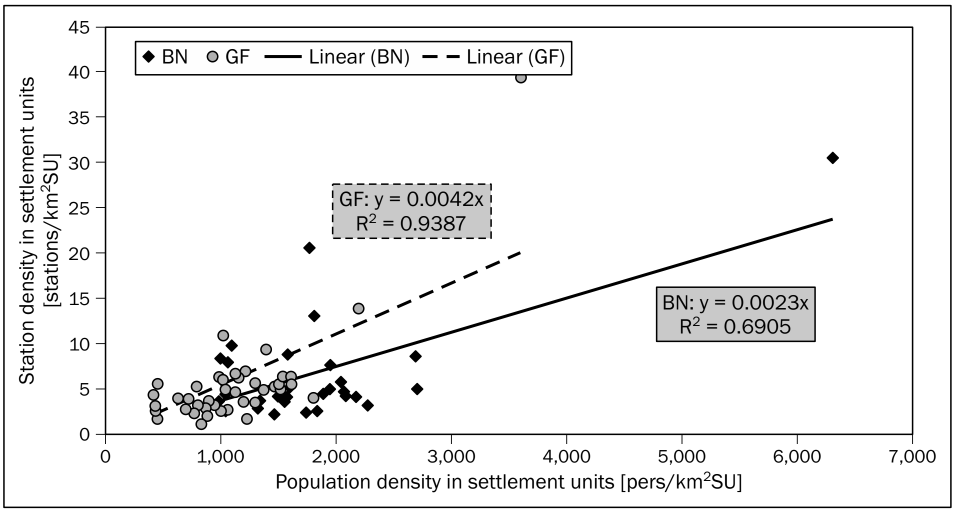

Figure 4 - Station density of municipalities over population density per municipality for GF and BN districts

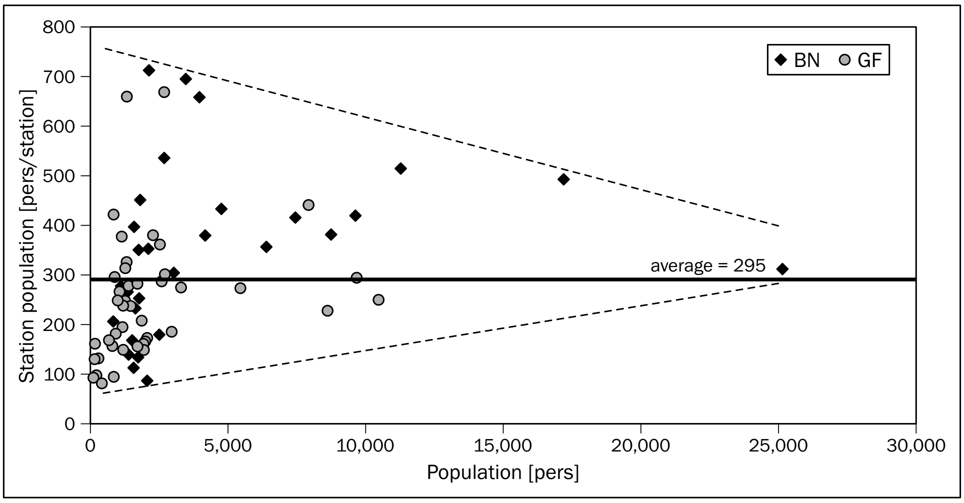

Figure 5 - Station population over population per municipality for GF and BN districts

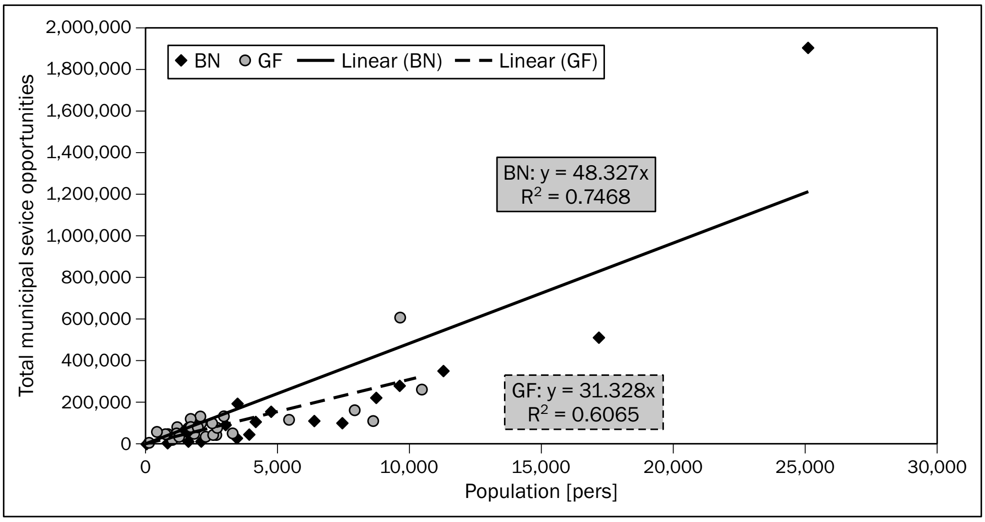

Figure 6 - Total service-opportunities per municipality over population

low the common average, whereas BN municipalities appear to be above. With increasing population size it focuses towards the common average of 295 persons per PT station. The average for the BN municipalities sub-set is 362 and for GF municipalities 249.

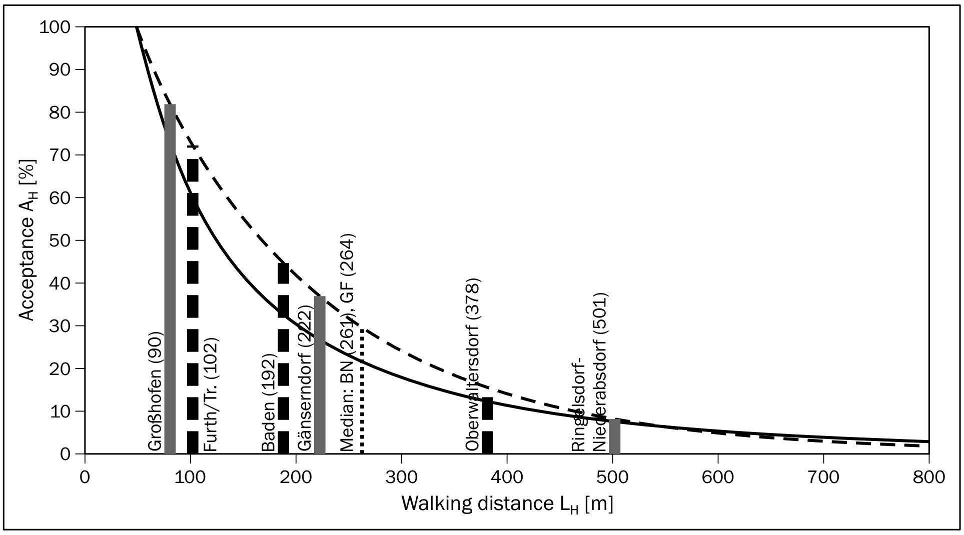

Figure 7 - Average access walking distance to stations calculated from average SU area per station, shown per district: minimum, maximum, district capital and district median. Dashed line: commuter trips; Full line: occasional trips; Light grey columns: GF district; Dashed dark grey columns: BN district. Modified after [27].

Figure 6 shows the total of service-opportunities per municipality over population and the corresponding linear approximation for GF and BN districts. In this case the district of GF lies beneath BN's performance. Both districts show remarkably high correlation coefficients ranging from 0.61 to 0.75.

As previous research shows [22, 23, 24, 25, 26], the coverage of settlements by PT networks and station locations has been an important issue in PT systems design and appraisal. In his seminal work on public transport station access, Walther [27] has derived distance-acceptance curves for two different types of trips: occasional and commuting. This is illustrated by a dashed line (commuting) and full line (occasional) in *Figure 7*. Within 600 m, for commuting trips the same access distance is more acceptable for

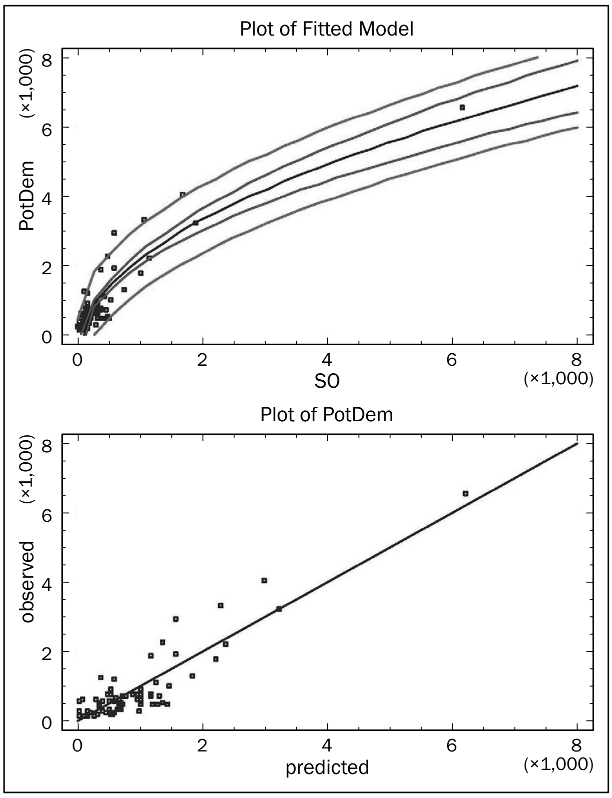

Figure 8 - top: Fitted model for PotDem = f (SO); bottom: observed values vs. values predicted by the model

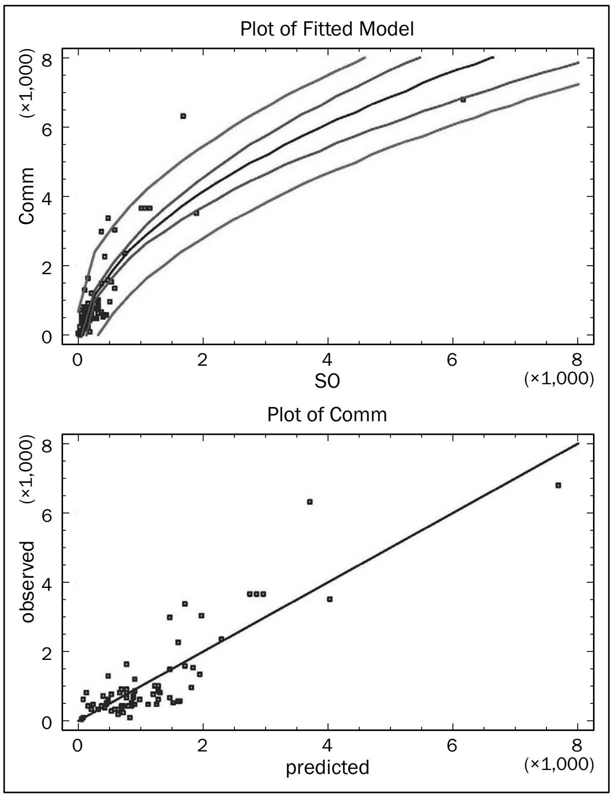

Figure 9 - top: Fitted model for Comm = f (SO); bottom: observed values vs. values predicted by the model

a higher proportion of people. *Figure 7* depicts the calculated average access distances of municipalities of both districts with Walther's commuting and regular trips curves. The average access distance is calculated from SU area per station based on a circular area. The shortest average access distances to stations are 90 m in Großhofen and 102 m in Furth/Triesting. Maximum values are Oberwaltersdorf with 378 m and Ringelsdorf-Niederabsdorf with 501 m. The medians of Baden and Gänserndorf districts are situated very close together: 261 and 264 m, respectively.

The regression analysis of potential demand *PotDem* with *SO* is shown in *Figure 8*, while *Figure 9* shows the regression analysis of *Comm* with *SO*. Both correlations follow a square root model (5).

$$y = a + b \cdot \sqrt{x} \tag{5}$$

Table 2 shows the model parameters, statistical measures and R^2 values for both models, while *PotDem* and *Comm* also correlate with each other satisfactorily in linear model with an R^2 value of 0.88 (not shown here).

Table 2 - Estimated parameters, statistical measures and R^2 for both models

Parameter	Estimate	Standard Error	T-Statistic	P-Value
Service-opportunities and potential demand				
a	-505.695	96.558	-5.237	0.000
b	85.679	4.994	17.158	0.000
R^2 = 0.81				
Service-opportunities and commuters				
a	-585.307	132.356	-4.422	0.000
b	105.398	6.845	15.398	0.000
R^2 = 0.77				

Since P-values in the ANOVA tables of both models are less than 0.01, there is a statistically significant relationship between *PotDem* and SO as well as between *Comm* and SO at the 99% confidence level.

4. DISCUSSION

The PT supply of municipalities in both districts varies distinctively, but not as much as popular belief of peripheral districts would have suggested pre-study. This is indicated by the small differences in per capita service-opportunities as shown in *Figure 3*. Also, this diagram depicts very clearly the orientation of service provision on commuter and school needs. On school weekdays and Sundays the per capita SO supply of both districts is very close. BN with 0.120 and 0.045 has the edge over GF's 0.116 and 0.037. The base supply is therefore of similar quantity. In the case of school holidays and Saturdays BN is much better served with PT runs than GF – 0.102 vs. 0.083 and 0.076 vs. 0.048. Services outside school days and base supply differ distinctively, here BN is better supplied. Albeit the GF district is more spread out, its areal supply with stations in terms of density per settlement unit meets the population density better than BN district (*Figure 4*). This hints at a more compact settlement structure within the municipalities of GF district. Interestingly, the station population of small municipalities scatters by a factor of about seven (*Figure 5*). Such a fluctuation with service-opportunities in small-sized municipalities would reflect their geographical positions: (a) small municipalities situated between larger ones, and (b) distance to larger municipalities (gravity trip distribution model). This could be explained by a location in between larger units and the more frequent services in between these. Now, as this is a similar case with station supply it remains to be studied what lies behind the fact that small municipalities close to Vienna have better station supply than more peripheral ones. *Figure 5* also, suggests the increasing population size stabilizing impact on relative supply parameters. One explanation may simply be one of matters of rates and proportions: an expectable fluctuation of absolute station numbers simply plays a bigger role on station population where the population and number of stations are small on the average in comparison to larger settlements.

In contrast to station supply, BN municipalities have a better provision with service-opportunities, i.e. bus and rail services, than GF municipalities do (*Figure 6*). The calculation of average walking distances to access stations (*Figure 7*) illustrates graphically that both districts lie pretty close when it comes to the coverage. Median values are almost identical and the capital and minimum values (Großhofen and Furth/Triesting) lie close to each other. Only maximum values (Oberwaltersdorf and Ringelsdorf) are separated by a calculatory access distance of 123 m. The acceptance diagram shows the potential of public transit to reach its customers according to chosen function – commuter or occasional trips. It is worth noting that some rural municipalities reach values as well or even better than in dedicatedly urban areas [26, 27], where PT station coverage area radii of 300 m or more are used for the calculation of passenger potential [28]. So average maximum walking distances to stops of 90 and 102 m pose impressively good values in theory. What of course is very different to urban areas is the much lower frequency of services in combination with high motorization rates, leaving most of the stations' passenger potential unexploited. It remains to be studied which district exploits this passenger potential better and if being better served with stations or with runs plays the more important role. Setting commuters in relation to service-opportunities shows that daily work commuters can be explained at a statistically significant level by service-opportunities. The adoption of the

PotDem concept in absence of actual passenger data and the use of model parameters from Valencia and Barcelona regional mobility surveys thus prove to be transferrable to the Vienna region.

5. CONCLUSION

In this study we have studied public transport supply parameters of municipalities in two districts in the Vienna region by assessing parameters like station density, service-opportunities, settlement unit density, commuters and by introducing a proxy named potential demand.

A strong opinion is persistent in suburban to rural regions that these may be less well served than others, and often the expectations of urban PT service quality and frequency to suburban or rural areas are applied. The systemic parameter analysis of service-opportunities, population, settlement unit area and potential demand puts an equality discussion on solid, evidence-based ground. Popular perception, even among transport experts is prone to misperceptions of demand comparisons over different territories. In both of our cases the commonly accepted view is that the more rural district of Gänserndorf has generally worse PT services to offer than the more suburban district of Baden. Our analysis proves this general notion to be wrong, and we have proven the picture to be more complex than expected.

The advantage of such a systemic supply analysis is that it does not only help to clarify a blurred picture in daily transport policy discourse on a regional scale but also provides a regional development planning tool for the analysis and comparison of public transport supply. The comparison of diverse areas is necessary especially under two perspectives: fair funding of PT base services of differing regions, and the regional planning equality/disparity debate. As real passenger data were not available for this research, we derived the proxy parameter potential demand from proven transport models and model parameters and used it for the verification which led to satisfying results. But future service-opportunity studies shall extend to include actual passenger data (per stop) instead, to gain more precise insight and correlate these for example within a multi-criteria model, e.g. with the average distance to access stations as another model parameter.

One limitation of this study is the lacking distinction between service-opportunities of road and rail-bound services, even though the data provided by VOR differentiates between different modes.

Although the models of potential demand and commuters already establish service-opportunities as a useful method, real ridership figures need to be added to increase the proficiency and explanatory value. Furthermore, additional supply parameters like the average number of transfers to destinations, location of stations (e.g. within major settlement areas) or minor municipalities between bigger municipalities are necessary to be incorporated in the development of this analysis method. We suggest applying a method with additional and improved data to potentially verify and eventually explain the convergence nature of station supply from *Figure 5*.

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ZUSAMMENFASSUNG

SERVICEFAHRTEN DES ÖV IM SPECKGÜRTEL – EINE SYSTEMISCHE ANALYSE VON ZWEI BEZIRKEN IM GROSSRAUM WIEN

Der öffentliche Verkehr in der Übergangszone zwischen städtischen und ländlichen Gebieten gerät aus Gründen der Finanzierung und Daseinsvorsorge vermehrt in den Fokus der Aufmerksamkeit. Die (wahrgenommenen) Angebotsunterschiede in entlegenen Gebieten werden dabei stark diskutiert. Wir untersuchen das Angebot des öffentlichen Verkehrs in den Gemeinden von zwei Bezirken in der Region Wien, Österreich, mittels der Kennzahlen Servicefahrten, Einwohner, Fläche der Siedlungseinheiten und potentielle Nachfrage. Die Servicefahrten eines Fahrplanjahres sind ein Parameter, der vom Verkehrsverbund für alle seine Haltestellen ermittelt wird. Die Analyse ergibt, dass die Angebotsunterschiede beider Bezirke entgegen der Erwartungen ausfallen und dass Servicefahrten eine geeignete Kennzahl zur systemischen Analyse der Versorgung mit öffentlichem Verkehr ist. Zum Abschluss werden die Notwendigkeiten einer Weiterentwicklung dieser Analysekenngröße diskutiert.

STICHWORTE

ÖV-Angebot; ländlicher Bezirk; Haltestellendichte; Servicefahrten; potentielle Nachfrage;

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