A new Approach of Park-and-Ride within Travel Demand Modeling

Thomas Veit*[1], Karl Hofer[1], and Martin Fellendorf[1]

[1]Institute of Highway Engineering and Transport Planning, Graz University of Technology, Austria

Short summary

Park-and-ride (PR) facilities provide parking lots near public transport stops to allow intermodal trips. In metropolitan regions intermodal trips are one measure to provide more sustainable mobility. However, modelling PR-trips in macroscopic travel demand models becomes difficult since two distinct modes are used within one trip. Most mode choice models require independent alternatives which is not the case with trips using private and public transport. This paper introduces a new approach of PR modeling within zonal based macroscopic travel demand modes. Zonal connectors are introduced with capacities representing the number of parking lots at a PR facility. Under saturated conditions this approach will lead to more realistic results than previous approaches. However, it is only applicable for cases with catchment areas by car near the trip origin. The advantages of modelling all demand strata outweigh the limitations due to the distribution of the parking space capacities among the traffic zones.
Keywords: travel demand modeling, zonal approach, demand of park-and-ride trips, connectors

1 Introduction

PR facilities represent linking points for intermodal trips with both transport and non-transport requirements. These should be included in the demand modeling. According to Guillaume-Gentil et al., there are four types of PR facilities. These are PR facilities at mobility centers near the center of the metropolitan area, PR facilities on the outskirts of the metropolitan area (near destination), PR facilities on the entrance roads to the metropolitan area (near origin) and PR facilities on the access roads to POIs. From a transport planning perspective, PR facilities close to the origin are preferable in terms of a reduction of the total traffic performance (Guillaume-Gentil et al., 2004). In addition, there are Remote PR facilities, a type that is especially used in Chinese cities (Liu et al., 2018). Ping and Jing distinguish between passive (e.g. lack of parking spaces in the city centre) and active factors (e.g. information service or savings on parking fees) in PR choice as well as the convenience of switching to public transport (Ping and Jing, 2008). Building on this, Ying and Xiang analysed the main influence factors for the choice of PR. The main motive for not using PR is overcrowded public transport, while the main motive for using PR is the lack of parking space at the destination (Ying and Xiang, 2009). Furthermore, Hamadneh and Esztergár-Kiss underline the importance of parking management systems at the PR facilities, due to an non-linear increase of average trip time by increasing the parking lot search time (Hamadneh and Esztergár-Kiss, 2022). Therefore, the modelling of the approach of PR demand modelling should give the opportunity to include all attributes and factors.
The national travel survey in Austria (bmvit, 2016) indicates the importance of intermodal trips with a share of 12% of all trips. The share of PR trips reaches 24% of all observed intermodal trips (combination of car, PT or bicycle trips). In total, the share of PR is rather unrepresented, as only 2.8% of all trips are done via a PR facility. If the reference is the PT as main mode of people living in non-urban areas, the share of PR trips increases to 13%. Thus, PR trips are a relevant influencing variable for the demand modeling of PT in non-urban areas (bmvit, 2016).
Demand modeling of intermodal trips and trips chains is a fundamental problem in travel demand modeling with a zonal approach unlike an agent-based model approach. Classical utility models of transport mode choice with uni-modal transport allocations can only capture intermodal trips to a limited extent. Varying approaches exist in literature within the zonal approach of travel demand modelling. These different approaches model different requirements and types of PR facilities. The analyzed approaches are PR demand model via connectors, via virtual links (Fellendorf et al., 2015) and the PTV tool for PR (PTV Planung Transport Verkehr GmbH, 2021). Connectors represent

a virtual link between a physical element of the network, in this case the stop as a node and the zone centroid (Cascetta, 2001). Figure 1 gives an overview over the analyzed approaches.

PR demand model approach via connectors

This rather simple approach directly matches a trip from the origin traffic zone toward an PR facility via a PT access connector with the same PT mode. Zone attributes and/or access times at the connector allow a different ways of modeling utilities for usual PT foot-connectors and PR-connectors. The connected zones are a predefined catchment area of the PR facilities. However, this approach does not consider any facility related properties, like parking lot capacity. In addition, no separate mode is introduced for PR. To determine the differences between the available modes, varying access times were assigned to the corresponding connectors. Therefore, every demand strata with PT access has access to PR, even the person groups without car availability. The travel demand is represented by the volume at the connector. In case of multiple connectors, the connector with the highest utility is selected.

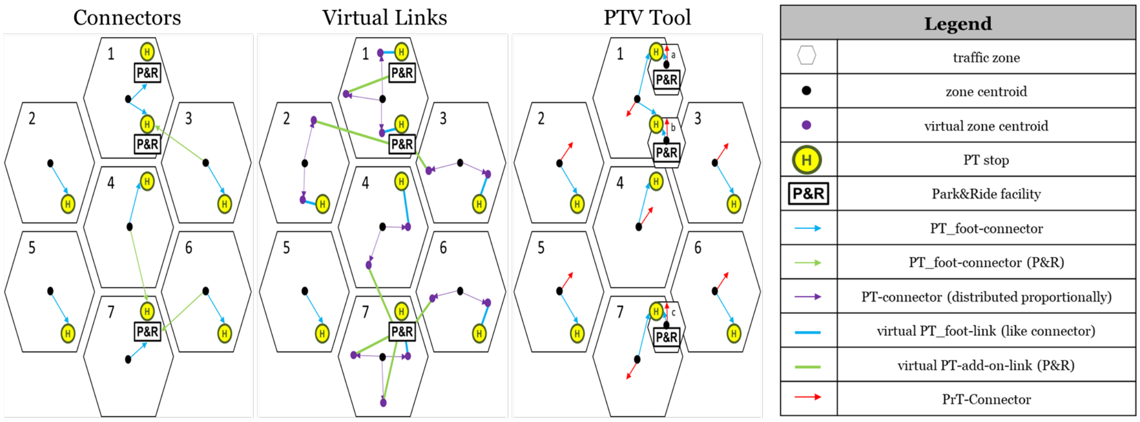

Figure 1: Three approaches to model PR by connectors or virtual links

PR demand model approach via virtual links

Compared to the previous described approach, this one is extended via virtual links and zone centroids. The development aims a finer zone network without an increase of the zone sum. Virtual zone centroids represent high population densities in the zone like municipalities, scattered settlements or other centroids. These subdivisions are connected to the PT service differently, via PT-pedestrian access or PR access. The share between the virtual zones is determined by a connector property. However, this determines the share between PR users and PT users with pedestrian access in advance.(Fellendorf et al., 2015)

PTV tool for PR demand modelling

Within the commercial software PTV Visum, an add-on for modelling PR facilities was developed. In comparison to the previous described approaches, this tool applies an independent demand model to model PR parking lots. In this approach PR facilities are modelled as zones with properties that influence the demand. In contrast to the explained approaches, PR users use the road network during their trip form the origin zone to the PR facility zone. Predefining and assigning an catchment area is not necessary. This approach guarantees that a user will take the PR facility with the best overall utility between origin and destination. Various attributes can describe one PR facility (e.g. specific parking space search time, capacity or capacity restrain function). To simulate PR properly, a new mode needs to be introduced, which includes a PrT leg and a PT leg. This allows to exclude person groups which do not have car availability in the mode choice model. The outgoing demand calculation is based on one demand strata. The overall demand and the traffic assignment is computed iteratively. This ensures that the outgoing demand is equilibrated by means of the capacity restraint (CR) function. There is no modelling of the return trip but the demand matrix is mirrored. Therefore, this approach can only model trip chains with three activities for the mode PR (e.g. Home-Work-Home). To incorporate PR trips into the overall demand matrix for PrT and PT, the respective share of their demand segment of the calculated PR demand matrix (PTV Planung Transport Verkehr GmbH, 2021).

Research Gap

The discussed approaches of modelling PR demand have substantial limitations, which need to be addressed in future research. The simple approaches via connectors or virtual links do not consider properties of PR facilities. This lack of a CR-function leads to demand, independent of capacity utilization. Additionally, the PR facilities have predefined catchment areas for the potential users. The complex approach from PTV does not include all trip chains in the demand modelling. This restriction leads to the fact that 25% of the trips are not modelled properly (bmvit, 2016). Therefore, we propose a new approach, which tries to combine the advantages and strength of the described approaches, while minimizing the disadvantages, like the lack of a CR-function or the long implementation and computing time.

2 Methodology

This section describes the developed PR modelling approach. It combines parts of the approaches described in section 1, while further aspects (e.g. capacity based limitations, parking usage distribution, etc.) are further looked at. In the following, these advances are discusses sequentially.
Two of the described approaches do not encounter any capacity related indicators, like the number of parking lots. This is an essential limitation. Hence, we consider a CR-function which is defined as an additional attribute PR-t_i for every zone. PR-t_i is defined as the travel time between the origin zone and the PT stop, see function (1). This attribute requires a distribution of the parking lots available at the PR facility to the surrounding zones.

$$\text{PR-t}_i = \frac{\sum cap_j}{d} * [(1 + a * \frac{q}{c * \sum cap_j})^b] + \frac{\sum_{k=1}^{n} t_k}{n} \tag{1}$$

Equation 1 where cap_j is the allocated PR capacity of the origin zone, d is a parameter to convert parking lots to travel time, a, b and c are model parameters, q is the current demand, t_k is the travel time between the origin zone and the PR facility and n reflecting the number of PR connectors. The first term $\frac{\sum cap_j}{d}$ describes the parking search time and walking time between the parking lot and the stop. This term should reflect the assumption, that thewalking time correlates with capacity utilization. The second term depicts the average travel time between the origin zone and the connected PR facilities. The travel time is computed based on the the access time for PrT $t_{access,PrT}$, a detour factor u the link length l and the average travel speed $v(l)$ each length, which is assigned to each link, see function (2).

$$t_k = t_{access,PrT} + \frac{l * u}{v(l)} \tag{2}$$

Alternatively, a CR-function could also be used to define the connector length. However, this approach was not chosen, since the model which is intended to be used for implementing PR facilites does not consider the connector length. In addition, we introduce a new PR mode including every PT systems except PT-pedestrian access. Thus, implausible person groups can be excluded in the mode choice.For all other person groups, we assign a PT utility function, whereby the origin zone attribute PR-t_i replaces the origin zone attribute PT-pedestrian access.
The parking lot distribution is similar to a defined catchment area. Basically this means a reservation of parking lot for settlements, towns or municipalities depending on distance and population. As shown in figure 2, zone 4 is connected to two PR facilities and gets assigned PR capacities based on the mentioned features. To compute this, we apply a modified gravity function (formula 3). $F_{i,j}$ is a force between zones i and j to allocate the capacities in the near vicinity. The parameter $b_{i,j}$ limits the forces locally. a_1, a_2, x_1 and x_2 are model parameter. The parameters m_i and m_j reflect the assigned capacities, $r_{i,j}$ is the travel time between the two zones i and j and the parameter k_i sets the diagonal in the force matrix and represents the population.

$$F_{i,j} = b_{i,j} * (a_1 * \frac{m_i - m_j}{r_{i,j}^{x_1}} + a_2 * \frac{k_i}{r_{i,j}^{x_2}}) \tag{3}$$

The forces are converted into parking lot capacities. Therefore, the force ratio is recalculated for each column. The row sums of the matrix multiplied by the capacity vector represent the new capacity. The forces and the parking lot distribution are determined iterativelly. This distribution method needs calibration regarding travel distances between origin zone and the used PR facilities.

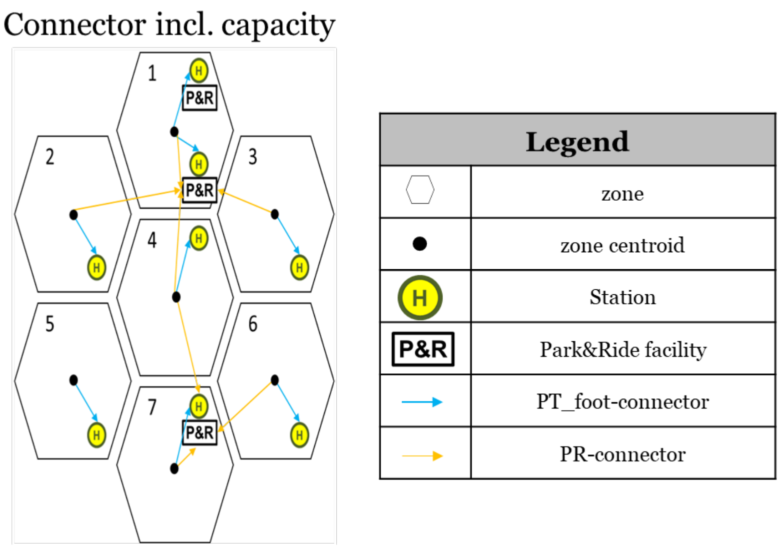

Figure 2: Systematic presentation of the new PR demand model approach.

The result of the mode choice is the PR demand and is the overall PR demand, which returns a demand matrix for all person groups with the source activity residential. Hence, a demand is only computed and can exist, if a parking lot capacity is assigned to a zone. For the destination zones, a parking lot capacity is not relevant. This requires further network adaption between the demand calculation and the traffic assignment. All connectors with PT-pedestrian access must also be released for PT-PR access. Otherwise, trips containing PR can not reach their destinations. This release must be deferred again before calculating the skim matrix.
This approach aggregates the data to the level of zones. This introduces difficulties for evaluating the demand, in particular if multiple stops are within one zone, as it can be seen in zone 1 in figure 2. In this case assumptions needs to be defined. Connecting all PR facilities to the zones seems not to be a proper solution, as the most attractive alternative (at least with the same destination) would always be selected in the traffic assignment (homo oeconomicus). Without fixing this problem, parking lot capacities would be shifting between PR facilities. If a zone would be connected to several PR facilities, see zone 4 in figure 2, the same problem would arise in the evaluation of the results.

3 Results and Discussion

Table 1 shows the results of the capacity utilization of PR facilities along a railway in southern Styria. The capacity utilization data of 2019 was provided in a quarterly basis by the ÖBB-Infrastruktur AG. The shown capacity utilization is the average of quarter two and four. More exact modelling results could be generated with further calibration, but it is obvious that both approaches can capture the actual state.
The PR demand modeling approaches via Connectors and via Virtual Links have quite similar advantages and disadvantages, see table 2. The big benefit of the approach via virtual links is the possibility to split zones regarding the access to PR. The demand modelling of areas with various scattered settlements benefits of this advantage. Therefore, less zones are needed while having a detailed PR demand model. Nevertheless, both approaches do not depend on capacity utilization. Parking lot capacity is not an influencing variable. Moreover, PR users on the outgoing trip can use a different mode to get back to their origin, what leaves their PrT at the PR facility.
The PTV tool does not require a predefined catchment area, as users choose the PR facility depending on their personal highest utility. Utility calculation uses several attributes, as the PR facility is a independent zone. Therefore the utility depends on capacity utilization and the demand results per PR facility. This allows to model a variety of PR facility types. However, an iterative process is needed to compute the results. Moreover, the computing time depends strongly on the amount of different demand strata utility matrices. This leads to one utility matrix for all person

Table 1: Results of PR demand modelling in capacity utilization

Stop	**capacity utilization [%]**	**PTV-Tool [%]**	**Connector incl. capacity [%]**
Feldkirchen-Seiersberg	94	94	88
Flughafen Graz-Feldkirchen	96	86	96
Kalsdorf bei Graz	88	85	88
Werndorf	70	69	65
Wildon	80	77	76
Lebring	75	70	73
Kaindorf a.d. Sulm	77	70	73
Leibnitz	82	78	82
Ehrenhausen	78	83	83
Spielfeld-Straß	62	60	65

groups without a possibility to change the the parameters of the utility function for the different PR related utilities, such as the parking search time. This matrix can only be changed with a constant or factorized in the mode choice per person group. The biggest disadvantage of this complex approach is the restricted number of trips within a PR trip chain. This also effects the demand strata, as the demand matrix is mirrored for the return trip, which assumes that the user will directly come back to its PrT. However, 25 percent of PR trips (four- or more part trip chains) are represented with three-part trip chains (bmvit, 2016). This occurs due to the calibration of the capacity utilization of the PR facilities.

The newly developed approach combines the advantages of the existing approaches. The PR users reach the PR facilities via connectors but the PR utility is dependent on capacity utilization. This requires the conversion of the PR facility attributes to the level of the zones in their predefined catchment area. The parking lot capacity of the respective PR facility is distributed to the zones in the catchment area. The PR demand depends on capacity utilization with this approach. However, due to the distribution of parking lots, difficulties occur in the PR demand if the catchment areas of PR facilities overlap too much. The results in PR demand must be checked for plausibility if a zone is connected to more than one PR facility. The available zone property of the PR capacity is the sum out of all distributed capacities of the connected PR facilities and this leads to a virtual shift of the parking lots to the PR facility with the highest utility. For this reason, this approach is suitable for distinct areas with regard to the origin-destination relationships between the PR facilities and the origin zone. Improvements are possible due to software developments and the usage of the intermodal traffic assignment tool of PTV. If the software offered the option of specifying the distribution of a transport mode between connectors, more than one connector per zone and also demand modelling of near destination used PR facilities would be possible.

None of the described approaches can model the PR demand without restricting important aspects. Accordingly, an assessment is necessary to evaluate the required attributes of each task and the specific area for PR demand modelling. Afterwards, the proper approach can be chosen.

Table 2: Comparison of the PR modelling approaches

Approach	Advantages	Disvantages
Connectors	short implementation time	-
	short computing time	-
	include all demand strata	unlikely demand strata as well
	-	PR demand is interpreted
	-	regardless of capacity utilization
	-	catchment area defined in advance
	-	one PR utility per zone
Virtual links	short implementation time	-
	-	longer computing time (PT procedure assignment)
	qualified demand interpretation	-
	subdivided zones as catchment area	-
	include all demand strata	unlikely demand strata as well
	-	one PR utility per zone
	-	regardless of capacity utilization
	-	catchment area defined in advance
PTV tool	-	implementation time
	-	computing time
	-	one utility matrix (from one demand strata)
	modelled demand (outgoing)	return trip: matrix mirroring
	depending on capacity utilization	-
	possibility to forbid demand strata	just three-part trip chains
	no predefined catchment area	-
	demand per PR facility	-
Connectors incl. capacity	-	implementation time
	computing time	-
	depending on capacity utilization	-
	all plausible demand strata	-
	one utility matrix per person group	-
	-	catchment area defined in advance
	-	demand may need special traffic assignment
	demand per PR facility (in case of simple catchment area)	demand per zone (in case of complex catchment area)

4 Conclusions

This paper presents a qualitative comparison of three existing PR demand modelling approaches and the methodology of a newly developed approach.

The different PR demand model approaches have various advantages and disadvantages and the application depends on the complexity of the catchment areas of the PR facilities. The PTV Tool is suitable for complex and overlapping catchment. The zones are not strictly connected to certain PR facilities. The benefits of this "free" users choice of PR facilities outweigh the restrictions of the permitted demand strata.

For less complex situations with rather simple PR catchment areas, the proposed approach is suitable. Simple catchment areas have one PR connection per zone due to a calibrated parking lot distribution. This requires the offered PR facilities to be used near origin, what is preferred from an transport planning view. The benefits of all plausible demand strata outweighs the inaccuracies due to the strict parking lot distribution. However, this approach has difficulties to model PR facilities in the outskirts of metropolitan areas well. Further software development could solve the underlying traffic assignment problem.

In the future, examinations will describe a precise assessment to measure the deviation of the results due to the different approaches (permitted demand strata or the capacity shift between the PR facilities).

Acknowledgements

I want to thank the ÖBB Infrastruktur AG, in person Herwig Riegler, for providing PR data for my research.

References

bmvit (2016). *Österreich unterwegs 2013/14*. Abteilung II / Infra 2: Infrastrukturplanung, Wien.

Cascetta, E. (2001). *Transportation Systems Engineering: Theory and Methods*. Kluwer Academic Publishers, Dordrecht.

Fellendorf, M., Haberl, M., Hofer, K., Strauß, P., and Sielemann, S. (2015). *ERB-Verkehrsmodellierung und Gesamtwirtschaftliche Bewertung: Bericht Teil 1: Verkehrsmodell VERMOSA 3*. PTV Transport Consult GmbH / Technische Universität Graz, Institut für Straßen- und Verkehrswesen, Karlsruhe / Graz.

Guillaume-Gentil, S., Camandona, C., Stucki, M., Baumgartner, P., and Lippuner, C. (2004). *Efficience énergétique des P&R*. Bundesamt für Energie, Bern.

Hamadneh, J. and Esztergár-Kiss, D. (2022). The influence of spent time at park-and-ride facility on the travel behavior of workers and shoppers. *Transportation Research Procedia*, 62:735–742.

Liu, Z., Chen, X., Meng, Q., and Kim, I. (2018). Remote park-and-ride network equilibrium model and its applications. *Transportation Research Part B: Methodological*, 117:37–62.

Ping, X. and Jing, W. (2008). Study on influence factors of park and ride choice behavior in expo 2010". *Communications Standardization*, 1:160–165.

PTV Planung Transport Verkehr GmbH (2021). *Verkehrsnachfrage: Modellierung von Park and Ride in einem Visem-Modell*. Karlsruhe.

Ying, H. and Xiang, H. (2009). Study on influence factors and demand willingness of park and ride*. *Second International Conference on Intelligent Computation Technology and Automation*, pages 664–667.