Extending Rural Public Transport Based on Mobility Demand. A Case Study about Planning a Transport-on-demand System in Leogang (State of Salzburg, Austria)

Maximilian Kranabetter[1,2]

[1]University of Salzburg, Austria
[2]Research Studios Austria

Abstract

In this project, location-allocation analysis and a spatio-temporal model of mobility demand were integrated into a decision-making tool for extending the public transport network by a transport-on-demand system. The temporal component of the mobility model was based on a survey of mobility behaviour which could be linked to spatial indicators of mobility demand (number of residents per 100m grid cell, a commuter matrix based on 250m grid cells, points of interest, and tourist accommodation). The case study focused on Leogang (Pinzgau, State of Salzburg). Twenty-three potential new locations for transport-on-demand stops were chosen in addition to the 17 existing public transport stops, so that as many demand points as possible would have access to a stop within 500 metres. The proposed stops would provide a public transport connection for the first time to 36.1% of the weighted origin–destination pairs within Leogang and between the municipality and other regions. This approach, which considers the accessibility of both origins and destinations of trips, is a versatile tool for public transport planning and is easily transferable to other municipalities with a similar structure.

Keywords:

location-allocation, mobility transition, rural mobility

1 Introduction

1.1 Motivation

Traffic volume in Austria has been increasing in recent decades (Tomschy et al., 2016). Transport planners have pointed out the negative effects of travelling by private car, including higher greenhouse gas emissions, air pollution and traffic congestion, while recognizing that choosing public transport instead of the car on as many trips as possible can benefit the environment, public health and the social fabric of communities (Badland et al., 2010, 2014).

However, the preference for public transport over motorized individual transport largely depends on its speed, accessibility and convenience (Badland et al., 2010, 2014; Chakrabarti, 2017). These factors are also directly correlated with the density of the settlement structure (Frank et al., 2021). There is often a positive feedback loop between investment in public transport, its quality, and its use by passengers in densely populated urban areas, and a negative one in rural areas or more dispersed settlements. According to Tomschy et al. (2016), Vienna has the highest modal split of public transport in Austria (38%), while peripheral districts have the lowest (8%). BMK (2016) classifies a political district as peripheral if fewer than 73% of its residents can reach the closest supra-regional centre (from a list of 26 centres in Austria and 16 outside Austria but close to the Austrian border) within 50 minutes both by public transport and by car.

1.2 Case Study

The area of interest of this project is the rural municipality of Leogang, located in the Pinzgau, part of the State of Salzburg. It had 3,307 residents on 1 of January 2019, and its dispersed settlement structure rendered it particularly suitable for a study on rural public transport. Furthermore, the mountainous terrain and access to ski lifts, hiking paths and trails for mountain biking make Leogang a popular tourist destination in both winter and summer.

Leogang was chosen as a pilot region within the ULTIMOB project (tbw research & netwiss, 2022), the goal of which is the development of innovations to close the gaps in the Austrian mobility system. In Leogang, a transport-on-demand system has recently been introduced that consists of two eight-seater vehicles that are hired by the municipality from a local taxi company and can be ordered via smartphone app or a phone call. Passengers can book trips between any two public transport stops within the municipality, including new ones in areas that did not previously have a public transport connection. For trips beyond the municipality, the shuttle can be used for the first or last part (i.e., covering the distance from the point of origin in Leogang to a public transport stop where the passenger changes to a train or bus, or vice-versa for incoming trips).

The preferred time and date of departure can be specified by the passenger. An algorithm implemented by the taxi company bundles requested trips if the routes and departure times are similar, and notifies passengers as to whether the shuttle can pick them up at their desired departure time (SVV, 2022).

Two research questions were formulated. In the first part of the research, investigation focused on how location-allocation algorithms can be used to optimize the locations of transport-on-demand stops so that as many demand points as possible gain access to public transport. Location-allocation algorithms are decision-making tools implemented in a GIS environment to calculate optimal locations for specific kinds of facilities (Ribeiro & Pais Antunes, 2002).

In the second part, we estimate the volume of trips that can potentially be covered by public transport before and after the implementation of the transport-on-demand system. Mobility

demand within a municipality (outgoing to, and incoming from other regions) was modelled based on an origin–destination (OD) matrix. The OD matrix includes all demand points within the municipality of Leogang and one entry for each region outside Leogang (Hochfilzen, and other areas further to the west; Saalfelden, and other areas further to the east). An OD pair will be marked as traversable by a specific means of transport if both the origin and the destination have access to a stop that is served by that form of transport. Calculating the accessibility to transport-on-demand systems is based on the new potential stops identified in the first part of the project.

2   Literature review

Badland et al. (2014) argued that accessibility of public transport should be measured using OD matrices, because public transport is only a viable option if walking distances both from the journey's origin to the boarding point, and from the exit stop to the final destination are reasonably short.

Transport-on-demand services contribute to the transition towards more sustainable mobility, or help assure access to alternative modes of transport for as many people as possible while reducing car dependency. The key advantage of transport-on-demand systems is their flexibility to operate only when and where there is demand, instead of being bound to fixed routes and timetables, while allowing requests with similar routes and departure times to be bundled (Brake et al., 2007). These services are particularly suitable for sparsely-populated rural areas, where it would not be feasible to operate regularly scheduled public transport at high frequencies (Frank et al., 2021; Hiess & Schönegger, 2015).

Modelling mobility demand using GIS is a versatile tool in transport planning (Buliung & Kanaroglou, 2007). In many studies, data from surveys where participants keep diaries of their activities and movements have been integrated into the models (Giménez-Nadal et al., 2018, 2021).

Location-allocation analysis has been used to find appropriate locations for services of different kinds in a wide array of public and private contexts (García-Palomares et al., 2012), because it allows real-life problems to be reduced to their essential elements and the adjustment of the parameters accordingly (Teixeira & Antunes, 2008).

García-Palomares et al. (2012) used location-allocation to find appropriate locations for bike rental stations in Madrid. After exploring different problem types, they set the type to 'Maximize Coverage' in order to provide access to as many potential passengers as possible within 200 metres. They pointed out that when the number of facilities is already high, increasing it even further leads to diminishing returns (García-Palomares et al., 2012).

3 Data

3.1 Infrastructural data

A graph of the whole country's transport infrastructure was provided by the Graph Integration Platform (GIP) of Austria. It is openly available, intersections are represented as nodes, street segments are represented as edges, and every segment contains the accessibility for different modes of transport (e.g., walking, cycling, cars or buses) as an attribute. Therefore the graph can be used for routing (ÖVDAT, 2021).

A dataset of public transport stops (two train stations and 15 bus stops) was used. The train stations are served by regional trains every hour; the bus stops are served by bus line 690. While 13 of the bus stops are located along the main highway and also have a frequency of one per hour in each direction, the other two stops are served only three times a day in both directions combined.

3.2 Spatial demand indicators

Population data from the Federal Statistics Office of Austria (Statistik Austria, 2022) were available based on a 100-metre grid; data from 1 January 2019 were used. Commuter data for October 2019 were also provided by Statistik Austria (2022), which listed the number of work and school commuters per OD pair, with a resolution of 250-metre grid cells. Points of interest were sourced from OpenStreetMap and the Geographical Information System of the State of Salzburg (SAGIS, 2022). A dataset of tourist accommodation from SAGIS (2022) was used.

3.3 Temporal demand indicators

Tourism in Leogang peaks twice, in winter and in summer; its low seasons are in autumn and spring. In 2019, the monthly number of overnight stays in Leogang varied from 114,994 in February (on average, 79.0% of guest beds were occupied) to 14,684 in November (10.1% of guest beds occupied on average) (Land Salzburg & Statistik Austria, 2023).

Open-source data from Österreich Unterwegs 2013/14 (BMK, 2016), a survey on mobility demand of a representative sample of the Austrian population (Tomschy et al., 2016), were used to model daily and hourly fluctuations in trip volume. Trips can be filtered by the professional occupation of the respondents, the region where they live, the purpose of the trip, the start and end time of each trip, as well as the municipality (or municipalities) where the trip started and/or ended.

According to the definition of BMK (2016), Leogang is located in a peripheral district. Because of this, only survey data sourced from peripheral districts were included in the model to make it more representative of Leogang. Table 1 shows the categories of the trips included in the model that were considered most relevant for modelling demand for public transport. Trips were further limited to ones leaving from or going back home, because they are easier to model

than multi-trip chains (e.g., a trip from home to work, followed by a trip from work directly to a leisure activity, and then going back home). This selection makes up about 72% of the total trip volume in peripheral districts (BMK, 2016).

Table 1: Purposes of trips, and estimated number of trips per person and day in peripheral districts (starting from home or coming back home only), according to BMK (2016)

| Purpose of trip	Target group	Estimated no. of trips per day (Mon-Fri / Sat / Sun)
Work commutes	employees only	1.42 / 0.34 / 0.20 per employee
School commutes	pupils/students only	1.25 / 0.01 / 0.02 per pupil/student
Shopping	entire population	0.31 / 0.51 / 0.03 per person
Other errands	entire population	0.28 / 0.29 / 0.17 per person
Leisure	entire population	0.31 / 0.55 / 0.66 per person
Visits	entire population	0.18 / 0.27 / 0.46 per person

The average number of daily trips per respondent to the survey is 2.71 on workdays, 2.49 on Saturdays, and 1.94 on Sundays. Peak mobility demand on workdays occurs between 7:00 and 8:00, mainly because of outgoing commuters, while commuters on their way back home are more spread out across the afternoon and evening (BMK, 2016), confirming the observation made by Giménez-Nadal et al. (2021).

4 Methods

Figure 1 shows how the different input datasets were used in the processing steps of the model. Before the location-allocation analysis could be run, candidate locations had to be generated and the demand points had to be weighted. The OD matrices link the temporal indicators (estimated trip frequency at specific points in time, differentiated by purpose of trip) to the spatial demand indicators.

As tourism plays a major role in Leogang but the survey data only represent mobility behaviour of residents, tourists' mobility had to be extrapolated. Data from the survey have also been used to estimate proportions of trips that cross the municipality's boundaries.

The model builds on the selection of stops produced by the location-allocation analysis. It also uses the GIP to calculate walking distances to the nearest public transport stop or directly to the destination.
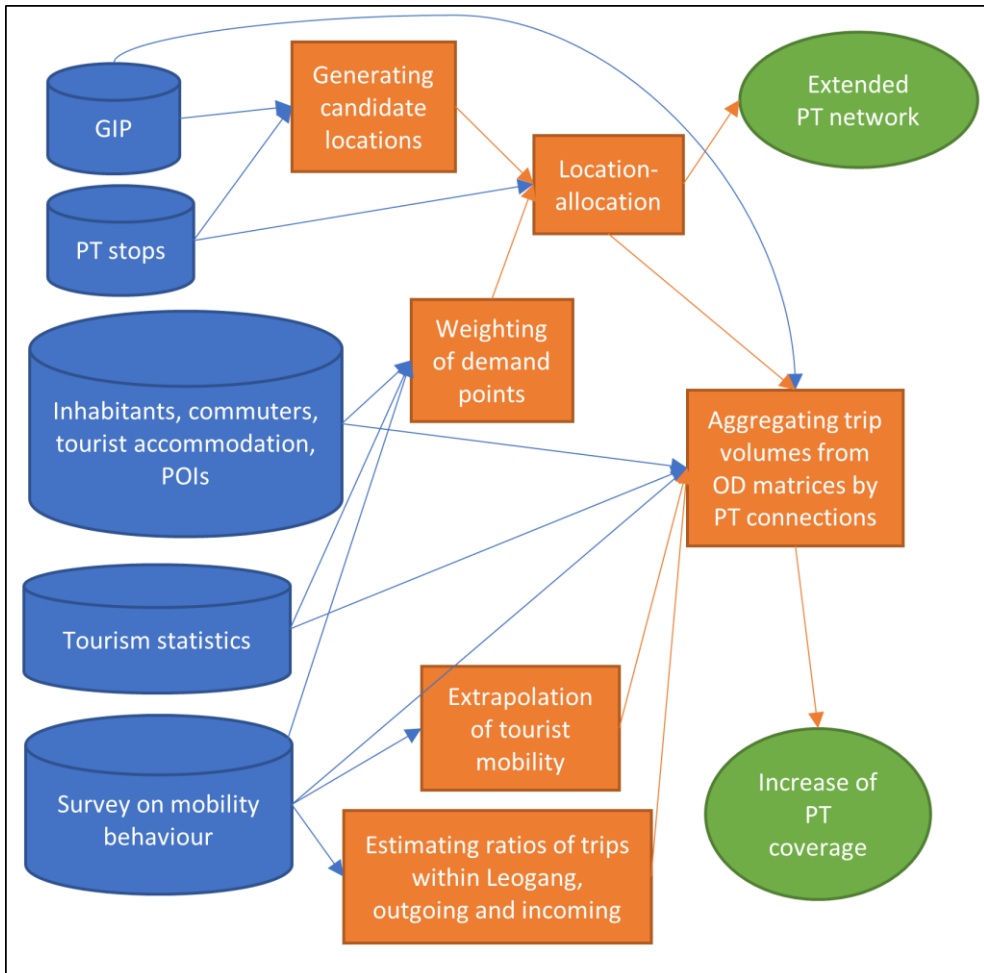
Figure 1: Flow chart depicting the data sources and processing steps leading to the results

4.1 Location-allocation analysis

A location-allocation layer was created in ArcGIS Pro to find suitable locations for transport-on-demand stops using the street segments of the GIP that are accessible for pedestrians, clipped to the extent of Leogang plus a buffer of ten kilometres.

Generating Candidate Locations

For this project, the 15 existing public transport stops were set as required locations that would also be served by transport-on-demand shuttles. In addition, two bus stops that are not currently served on a regular basis were also set as required stops, leading to a total of 17. Using the tool Generate Points Along Line, points were created every 20 metres along the

road network that is traversable by buses. Only those further than a 300-metre walk from a required stop were included as candidate facilities.

Weighting of demand points

Demand points were weighted according to the estimated number of trips starting and ending at that location per day. Residents were weighted with the average 2.07 trips per day, starting or ending at home, per person.

According to Tomschy et al. (2016), employed people, on average, tend to make more trips per day than the population as a whole. Because outgoing commuters already count as residents, 0.50 additional demand units were added to outgoing work commuters. Incoming work commuters (i.e., returning home) were attributed 2 demand units. Weighted demand was raised to 2 (outgoing) and 4 (incoming) for school commuters, because they tend to rely on public transport the most (BMK, 2016).

Tourist accommodation was given a demand weight of 1.11 units per bed according to the average occupancy rate (Land Salzburg & Statistik Austria, 2023).

Finally, the weights for points of interest were derived from the estimated number of trips per person per day by purpose (shopping, other errands, and leisure), the number of residents and average number of tourists present in Leogang, the number of points of interest in Leogang, and their estimated relative importance. This led to weight factors of 37.5 – 150 demand units for shops, 23.5 – 94 units for points of interest with the main purpose of other errands, and 34.5 – 138 units for leisure establishments. Demand located near the top stations of ski lifts was redistributed to the bottom stations.

Setting problem type and number of facilities

Of the seven available problem types for location-allocation analysis in ArcGIS Pro (ESRI, 2022), 'Minimize Locations' and 'Maximize Coverage' best reflect the first research question. Another approach that seemed interesting was 'Maximize Attendance', because it gradually lowers the demand weight that is allocated to a facility until the cut-off distance is reached, thus favouring the selection of facilities close to those demand points that have the highest weighted demand.

The location-allocation analysis was run separately for each means of public transport (train, bus and transport-on-demand) to determine whether a demand point has access to a stop, and if so, which stop is the closest. In all runs, the problem type was set to 'Maximize Coverage'. Because regional trains were classified as being preferred to buses (Hiess, 2017), the acceptable walking distance to the nearest train station was estimated as being greater than that to the nearest bus stop.

The analysis was run once for each means of public transport. In the first run it was determined which demand points have access to a train station within 1,250 metres, and which one is the closest. In the second run, the analysis was repeated with the 13 regularly served bus stops and a lower cut-off distance of 750 metres. In the final run, all existing public transport stops plus

the candidate locations were added to the model. The existing public transport stops were set as required facilities to be included in the solution. The cut-off was further lowered, to 500 metres. This final run determined the optimal selection of transport-on-demand stops.

4.2 Modelling mobility demand

Extrapolation of tourists' mobility

Tourist mobility was extrapolated from Österreich Unterwegs survey data and was assumed to consist only of shopping trips, other errands, and leisure activities. The number of shopping trips made by tourists was estimated to be similar to that of locals; the number of other errand trips was estimated to be about half that of local people. In accordance with the model of Fellendorf et al. (2015), who also modelled tourist mobility demand and put special emphasis on leisure trips, the volume of leisure trips of tourists per day (regardless of the day of the week) was assumed to be similar to the volume of leisure trips and visits of locals on Saturdays and Sundays combined. Österreich Unterwegs (BMK, 2016) differentiates between visits (a special form of leisure trip) and other leisure trips, but as visits are not relevant for tourists, both of these categories are counted towards tourists' leisure trips.

Estimation of the ratios of trips within, outgoing from, and incoming to Leogang

The demand for shopping trips, other errands, leisure activities and visits was estimated at each point. The estimates took into account whether a trip started and ended in the same municipality or not (information taken from the Österreich Unterwegs survey (BMK, 2016)). For shopping trips, other errands, leisure trips and visits, the only trips from the survey considered were those that originated in municipalities with 2,500–4,999 residents in peripheral districts. The proportions of trips staying within the same municipality and those that had their destination outside were assumed to closely resemble the patterns of Leogang for each trip purpose (commute, other errands etc.). By filtering out trips that have their destination in municipalities with 2,500–4,999 inhabitants and are located in peripheral districts, the volume of incoming trips to Leogang compared to that of trips originating in Leogang could be modelled.

The trip volume between Leogang and other municipalities in Austria was differentiated into four regions: Saalfelden (neighbouring municipality to the east), other municipalities further east, Hochfilzen (neighbouring municipality to the west), and other municipalities further west.

Aggregating trip volume by public transport connections based on origin–destination matrices

All possible connections between the 800 demand points in Leogang and the four regions outside the municipality were represented in an OD matrix. The commuter matrix already gives an insight into the origins and destinations of work and school commuters; the demands of other categories was estimated according to Equations 1, 2 and 3 (see below).

For shopping trips, other errands, leisure activities and visits within Leogang, the demand-inducing demographic indicator at the origin (Dem_{Orig}: residents or tourists) was multiplied by the demand-attracting potential at the target location ($Pot_{Dest,Cat}$: points of interest for shopping, other errands, leisure activities, visiting other residents). This was divided by the sum of demand-attracting potentials throughout Leogang ($Pot_{Leo,Cat}$) and multiplied by the ratio of trips of the specific category assumed not to go outside the municipality ($Ratio_{Leo,Cat}$) (**Fehler! Verweisquelle konnte nicht gefunden werden.**). The demand-attracting potential of individual points of interest in Leogang is derived from the demand weights assigned, as explained in section "Weighting of demand points". Ratios of trips that stay within Leogang, or cross into/come from a different region, are derived by filtering the trips from the Österreich Unterwegs data by municipality of origin and destination (section "Estimation of the ratios of trips within, outgoing from, and incoming to Leogang").

$$OD - Pair_{within} = Dem_{Orig} * \frac{Pot_{Dest,Cat}}{Pot_{Leo,Cat}} * Ratio_{Leo,Cat} \qquad (1)$$

Outgoing trips from Leogang of the same category were calculated by multiplying the demographic indicator of the origin (Dem_{Orig}) with the ratio of trips of the same category that are estimated to go to the destination region ($Ratio_{Dest,Cat}$) (**Fehler! Verweisquelle konnte nicht gefunden werden.**).

$$OD - Pair_{outgoing} = Dem_{Orig} * Ratio_{Dest,Cat} \qquad (2)$$

Incoming trips are calculated based on the total potential number of trips coming in from another municipality in relation to the trips being generated in Leogang (internal and outgoing trips combined). The total number of residents in Leogang (or guest beds for tourists, Dem_{Leo}) was multiplied by the ratio for the region of origin ($Ratio_{Orig,Cat}$). This was then multiplied by the estimated attracting potential of the destination point ($Pot_{Dest,Cat}$) as a fraction of the total attraction potential of Leogang ($Pot_{Leo,Cat}$) (**Fehler! Verweisquelle konnte nicht gefunden werden.**).

$$OD - Pair_{incoming} = Dem_{Leo} * Ratio_{Orig,Cat} * \frac{Pot_{Dest,Cat}}{Pot_{Leo,Cat}} \qquad (3)$$

Using an 'OD Cost Matrix Analysis Layer', it was determined that 83,748 of the 640,000 OD pairs within Leogang can be accessed by a direct walk of 1,250 metres or less. OD pairs were marked as accessible by train if both the origin and the destination are within a 1,250-metre walk of a different train station. The same process was repeated for bus stops, with a threshold of 750-metres walking distance, and for transport-on-demand stops (500 metres).

From the train stations, all regions (Saalfelden, further east, Hochfilzen, further west) can be accessed directly. The bus 690 provides a direct connection between the thirteen bus stops in Leogang and to two neighbouring municipalities, Saalfelden and Hochfilzen.

Transport-on-demand shuttles can be used for direct trips between any two public transport stops in Leogang. On outgoing trips to another municipality, these shuttles can be booked to

a stop where the passenger can transfer to a train or other bus going to that municipality. Incoming passengers from other municipalities can use the shuttles to cover the last part of their journey to their destination in Leogang after arriving at a train station or bus stop.

5 Results

5.1 Selection of transport-on-demand stops

In the 'Minimize Locations' approach (cut-off distance 500 metres), all demand points within 500 metres of an existing stop or a candidate location (96.8% of weighted mobility demand) were allocated to the smallest possible number of stops. In this case, the solution included 60 stops (the 17 required stops and 43 of the candidate locations).

When setting the problem type to 'Maximize Coverage' and the number of facilities to 40 (the 17 required stops and 23 additional candidate locations), the optimal selection of stops could still provide access to transport-on-demand services within 500 metres to 94.7% of the weighted demand.

When setting the problem type to 'Maximize Attendance' and raising the cut-off distance to 1,250 metres to account for the fact that less weight will be allocated if the chosen stop is located further away, the resulting distribution gave an over-supply of stops in the centre of Leogang, while sparsely populated areas saw hardly any improvement.

Because the 'Maximize Attendance' approach does not effectively improve the public transport connections of remote areas, which is the main goal of transport-on-demand services, and a high number of chosen stops (as in the 'Minimize Locations' approach) leads to diminishing returns, the decision was made to proceed with the 'Maximize Coverage' approach and 40 stops in total. These already cover a reasonably large proportion of the demand points that can be reached within 500 metres.

Figure 2 shows the existing public transport stops together with the 25 additional stops to be served by the transport-on-demand service. Before the implementation of the new plan, only about 79.5% of the weighted demand points had access to public transport; 24.2% had a train station within 1,250 metres and 75.0% a bus stop within 750 metres, their catchment areas overlapping slightly.

In the new plan, all 40 stops will be served by on-demand services; as mentioned above, about 94.7% of all weighted demand points in the municipality will be within 500 metres of a transport-on-demand stop. Because other means of public transport were assigned a greater walking distance, this leads to a total of 95.5% of the weighted demand points being covered, a sharp increase from before.
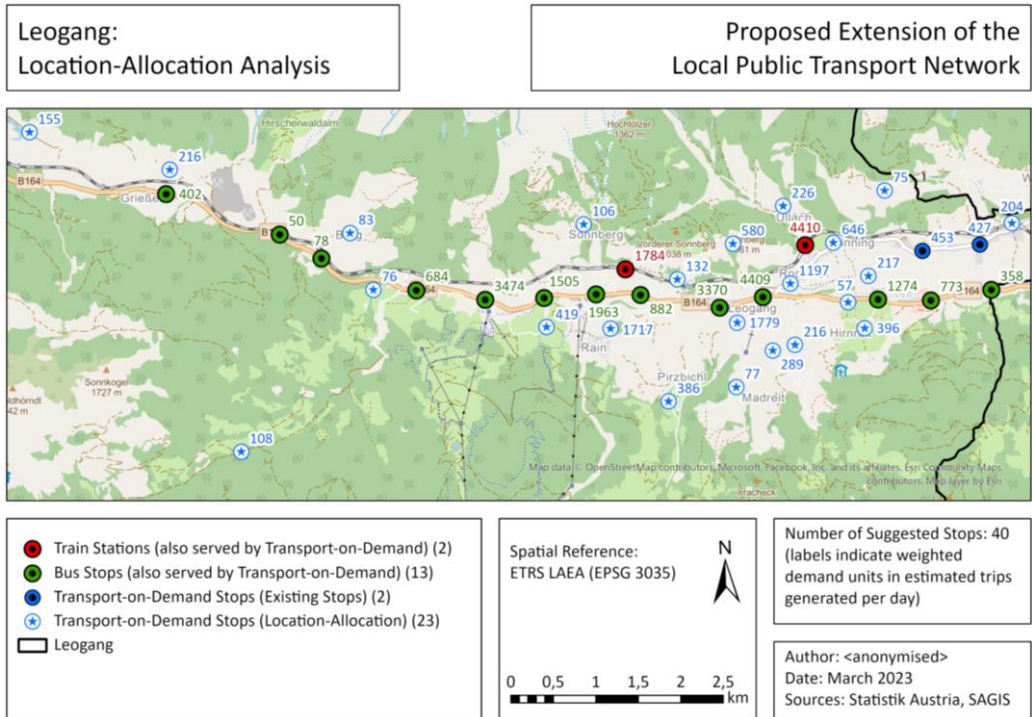
Figure 2: Final selection of transport-on-demand stops and the existing public transport stops

5.2 Accessibility by public transport of origin–destination pairs

Figure 3 shows the estimated average trip volume per hour that has access to each means of transport. The time slot 16:00 to 16:59 on a working day in February was chosen as arepresentative example because of the expected high trip volume (1,592 trips per hour within Leogang, outgoing from the municipality, and incoming from other regions). Trips by tourists, points-of-interest related trips by locals, and work commuters returning home make up the largest segments of the trip volume at that time (Figure 3).

A large portion of the trip volume (36.1%) did not have a connection by public transport before but could potentially be covered for the first time after the implementation of the new shuttle. Even more trips (43.2%) already had a public transport connection and will benefit from the additional option of using the new shuttle in the future, thus improving their connections. Those trips that can already be made by regularly scheduled public transport, but whose origin and/or destination is located more than 500 metres from a transport-on-demand stop (0.5%), did not see any significant improvement. Trips estimated to be shorter than 1,250 metres (11.8%) can be walked directly and are therefore not dependent on public transport. Finally, just 8.3% of trips will still be without a connection to public transport.

These numbers fluctuate slightly across different time periods because the categories of trips exhibit varying spatial patterns and peak at different times.
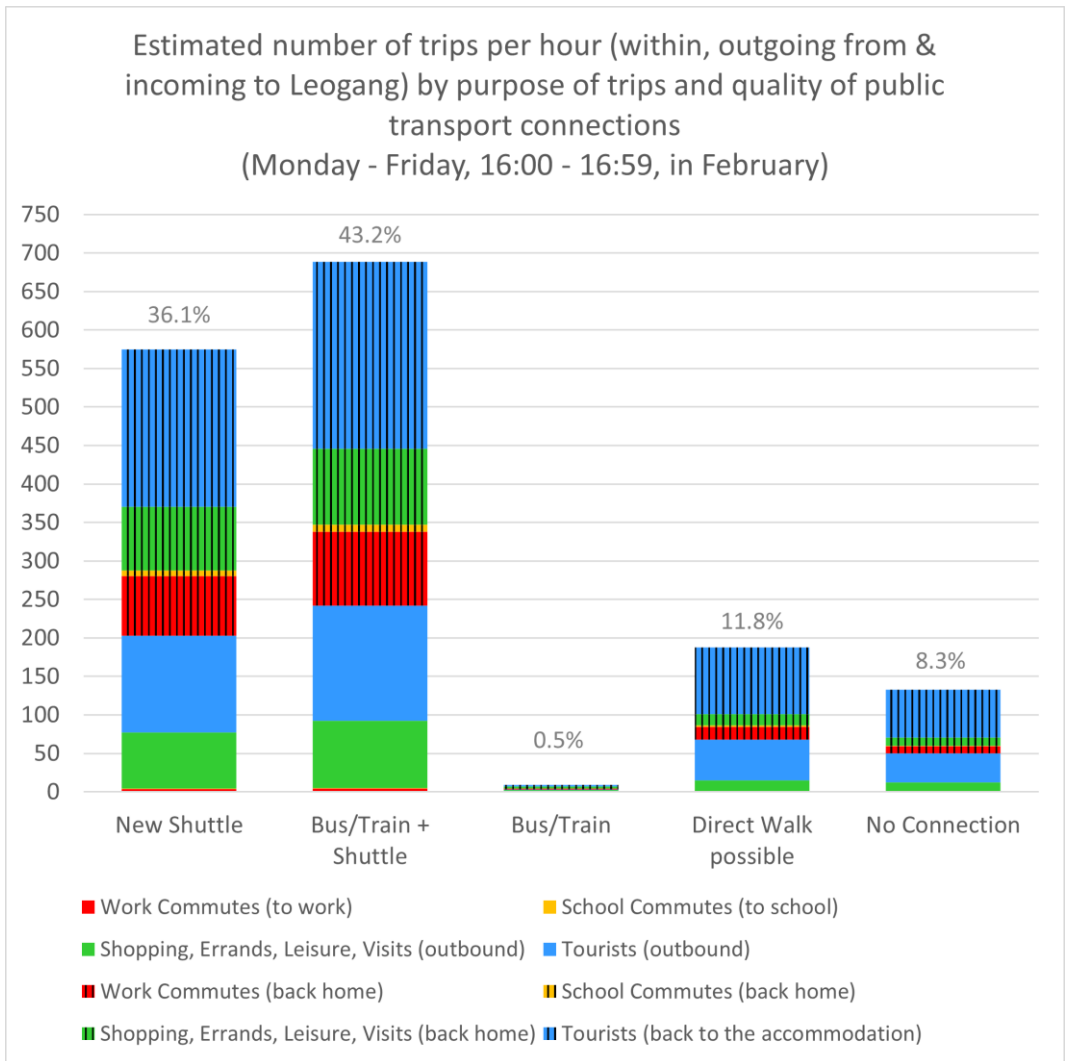
Figure 3: Estimation of trips per hour in the late afternoon on a workday in February after implementation of on-demand services

6   Discussion

The transport-on-demand stops chosen by the location-allocation analysis are well spaced out and located far enough from existing public transport stops to significantly extend the catchment areas of the public transport network. Trying out different problem types and

different numbers of stops showed that the 40 chosen stops already cover a very high proportion of weighted demand; there would not be much more improvement if the number of facilities was increased further. However, it might be reasonable for planners to adjust the locations of some of the stops in the final selection, according to local conditions (e.g., walkability of the surrounding area, proximity to intersections).

Giving a new public transport connection to 16.0% of weighted demand points leads to 36.1% of all estimated mobility demand within Leogang and between the municipality and other regions being covered by public transport for the first time. This confirms the importance of accessibility as a measure that takes into account both the origin and the destination, as pointed out by Badland et al. (2014). The reduction of weighted OD pairs without a public transport connection to 8.3% further emphasizes the flexibility of transport-on-demand services and their suitability for a rural municipality with a dispersed settlement structure like Leogang.

Only a small fraction of the trips shown in Figure 3 will be covered by public transport because of its low modal split in peripheral districts. While 51.1% of school commuters use public transport, the modal split among work commuters is just 8.5%, and even lower for shopping trips, other errands, leisure activities and visits (2.0%–3.1%) (BMK, 2016). Higher frequencies of connections and shorter walking distances to the closest stop make potential passengers more likely to use public transport. However, it is difficult to establish a direct link between quality of public transport and its modal split because other factors (e.g., the integration of individual bus lines and on-demand shuttles into the existing public transport network) also play a role (Badland et al., 2014).

When applying this approach to larger areas, some parameters might have to be simplified due to the increasing complexity, but for municipalities of similar size, structure and public transport connections to Leogang's, it can be transferred easily.

7   Conclusion and Outlook

This project created a highly suitable tool to facilitate the decision-making process of public transport planners. The transport-on-demand shuttle has already been implemented in Leogang (in September 2022); and in February 2023 the number of stops was increased to 39, which is almost equal to the number suggested in this paper. Many of the new stops were created at locations similar to those suggested by the model. In other cases, the locations were changed slightly according to local road conditions; others were created at points that had not been covered by the input dataset, but which are highly relevant for mobility demand (e.g., the kindergarten) (SVV, 2022).

Leaving out certain trip categories, such as business trips, giving somebody a lift, and multi-trip chains, made it easier to accurately model the spatial and temporal patterns of the remaining categories, but reduced the sample size of the data from Österreich Unterwegs to 72% (BMK, 2016). This created a trade-off between comprehensiveness and accuracy.

In follow-up projects, it would be interesting to use the automatically sourced data on numbers of passengers to monitor overall demand. This could serve as a guideline for transferring the approach to other municipalities with a similarly dispersed structure. Tracking the most popular routes could also help planners to consider incorporating transport-on-demand stops into new, regularly scheduled bus lines. Finally, conducting a survey among passengers about whether they substituted car trips with the new shuttle, or whether the shuttle has incentivized them to travel more, could be useful for estimating any reduction in the number of kilometres driven by car and the amount of greenhouse gases that have been saved in the process.

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