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Analyzing the Accessibility of Trolley Bus Stops in the City of Salzburg

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Abstract

Public transport promotes sustainable mobility by enhancing connectivity, safety, comfort and health. The location, type, condition and spacing of stops play a pivotal role in determining the accessibility to public transport. Poor accessibility to public transport can lead to increased cost and time of travel, poor mobility, traffic congestion and social exclusion. This study uses Multi Criteria Analysis to provide a holistic measure of accessibility in terms of Transit Accessibility Index (TAI) for all the trolley bus stops in the city of Salzburg. Five quantitative indicators are combined and weighted appropriately to obtain the final accessibility score. An overall accessibility assessment is performed to further classify the bus stops into five performance categories based on their final accessibility score. Ideal Point Method is employed to determine the values of indicators for the ideal bus stop and compare the values with those of the existing stops. The result from the analysis shows that the most accessible trolley bus stops are located in the core region of Salzburg city near the city center and the main train station. This kind of analysis is crucial for sustainable transport planning and thus helps to promote smart mobility and better habitability of the city.

Keywords: *Accessibility, Multi Criteria Analysis, Public Transport, Transit Accessibility Index*

1. Introduction

With the hike in the price of fuel and rise in environmental emissions, the significance of public transport is constantly increasing. The government of different countries are investing more on their public transport system and encouraging their use in order to reduce the economic and environmental burdens caused due the excessive usage of private vehicles. Public transport promotes sustainable mobility by enhancing connectivity, safety, comfort and health (Saghapour, 2016). They serve passengers of all age groups and transfer large number of people within considerable distances.

A public transport system is particularly characterized with its mode of operation, routes and stops (Mou et al., 2020). The stops serve as transit hubs that facilitate the interchange between different routes for a variety of trips including short haul transits, city transits or regional transits. The location, type, condition and spacing of the stops play a pivotal role in determining the accessibility to public transport.

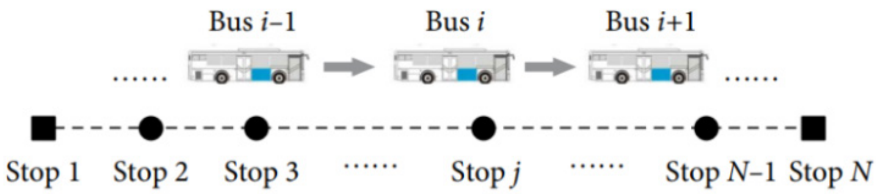


Figure 1: Public transport system (Mou et al., 2020)

Public transport stops are often set down independently without giving proper thought to the experience of waiting there and the relationships between the stops and their surroundings (Alexander et al., 1977). In almost every public transport system, some stops are improperly located and therefore become challenging to be accessed particularly by old age people and people with disabilities. Poor accessibility to public transport can lead to increased cost and time of travel, poor mobility, traffic congestion and social exclusion. This makes public transport less attractive, ultimately pushing people away from using them. Therefore, for efficient and reliable public transportation, it is necessary to evaluate which stops are accessible, which are not, which need to be redesigned and which need to be relocated.

Several methodological approaches have been designed for evaluating public transport accessibility such as the Structural Accessibility Layer (SAL) and the Public Transport Walking Accessibility Index (PTWAI), both of which employ location-based methods to calculate accessibility (Albacete et al., 2017). The Area Public Transit Accessibility (APTA) is another approach that evaluates accessibility based on service range of transit network and passenger travel behavior (Yan-yan et al., 2016). Another approach is the Local Index of Transit Availability (LITA) that measures accessibility in terms of the intensity of local transit service (Mamun, 2011). However, limited research has been done in the prevailing approaches to assess the attractiveness of urban public transport addressing multi-criteria evaluation categories such as transit service, built environment, stop quality, etc. This study provides a holistic measure of accessibility by calculating the Transit accessibility Index (TAI) combining five different accessibility indicators weighted appropriately to obtain the final accessibility score for all the trolley bus stops in the city of Salzburg. This approach is particularly suitable as it also incorporates the Ideal Point Method (IPM) to determine the values of indicators for the ideal bus stop and compares these values with those of the existing stops.

Accessibility is a multi-scope concept to shape the public transport stops (Corazza & Favaretto, 2019). Different transport literatures stress on different concepts of accessibility depending on the purpose of their research. Accessibility can be broadly defined as the ability to travel between different activities (Vuchic, 1999). Sometimes, it is also linked to convenience and thus defined as the ease to reach goods, services, destinations (Littman, 2017). The term accessibility also stresses equally on the concept of general proximity in terms of time of all points to a given facility (Lynch, 1995). Some authors have also defined it as the measure of quality and operational effectiveness of a community (Grava, 2003). Accessibility is often found associated with proximity using the terms such as "within walking distance" or "walkable" (Handy & Niemeier, 1997). Furthermore, accessibility can also be linked to individual perceptions such as the intensity of possibility of interaction (Hansen, 1959) or a mix of comfort, convenience and safety (Ardeshiri et al., 2018).

Figure 2: Multi-faceted definition of accessibility

In general, accessibility is associated with a place of origin and destination. A place with "high accessibility" is the one from which many destinations can be reached, or destinations can be reached with relative ease (Juremalani & Chauhan, 2018). Lower accessibility on the other hand implies relatively higher cost, time and effort required to reach a destination.

2. Research Methodology

2.1 Study Area

The study area for this analysis is the city of Salzburg. It is the fourth largest city in Austria with an area of 65.68 sq. km and a population of 155,416 inhabitants (Statistics Austria, 2022). The city lies on the banks of the river Salzach, at the northern boundary of the Alps. It is the capital of the federal state of Salzburg and is comprised of 24 districts and 3 landscape areas. The city has a remarkable history and ancient civilization mostly popular for tourism and educational activities. It is the birthplace of influential composer Wolfgang Mozart and famous scientist Christian Doppler.

Figure 2: Multi-faceted definition of accessibility

The trolley bus system is the most popular means of public transport in the city of Salzburg. This system is owned and operated by Salzburg AG. 12 trolley bus lines run through the city with 194 stops serving a route length of 146.45 km. A total of 123 trolley buses are operational that carry approximately 43 million passengers per year (SalzburgAG, 2022). This system is electrically powered and therefore maintains an energy efficient, pollution free and environment friendly mobility across the city of Salzburg.

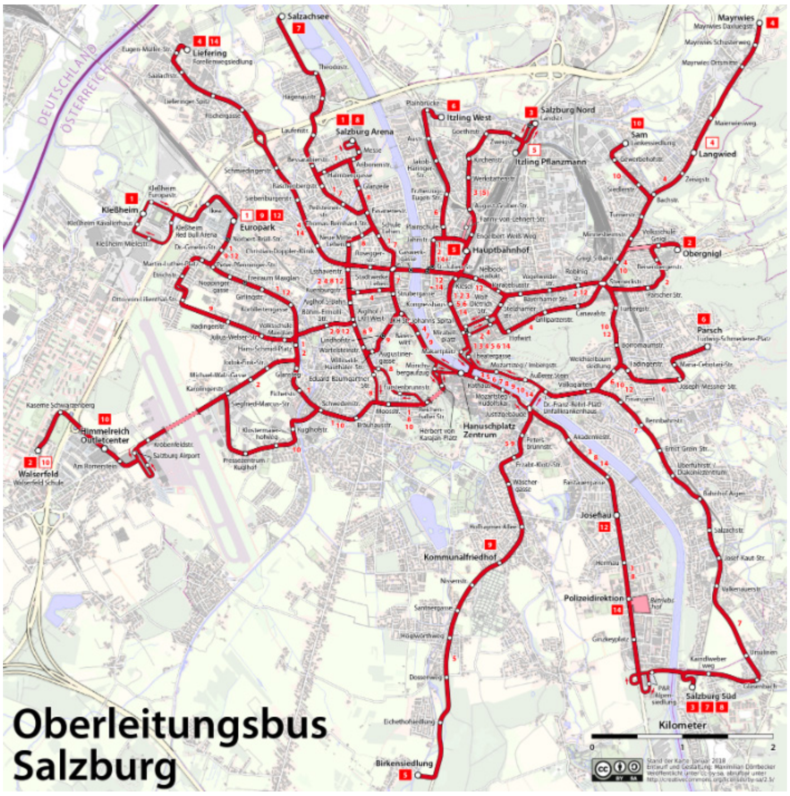


Figure 4: Salzburg trolleybus system map, 2017

2.2 Datasets

The following five datasets have been used for this analysis. While most of the datasets were freely available in ready-to-use format, some of these still required preprocessing steps i.e., georeferencing and digitization.

- Administrative Boundary of Salzburg City
- Salzburg Trolley Bus Lines
- Salzburg Trolley Bus Stops
- Population Point of Salzburg [100m Grid]
- Building Footprint of Salzburg

2.3 Methodology

This analysis is based on Multi Criteria Analysis (MCA) in which five quantitative indicators are used to determine the accessibility of the trolley bus stops in the city of Salzburg. A multi-criteria model for the indicators is used similar to a case study in Nomentano district in Italy. The final result is a single parameter, the so-called Final Accessibility Score, describing the accessibility of each stop, according to its characteristics and those of its surrounding environment, synthesized by the indicators constituting the Transit Accessibility Index (Corazza & Favaretto, 2019).

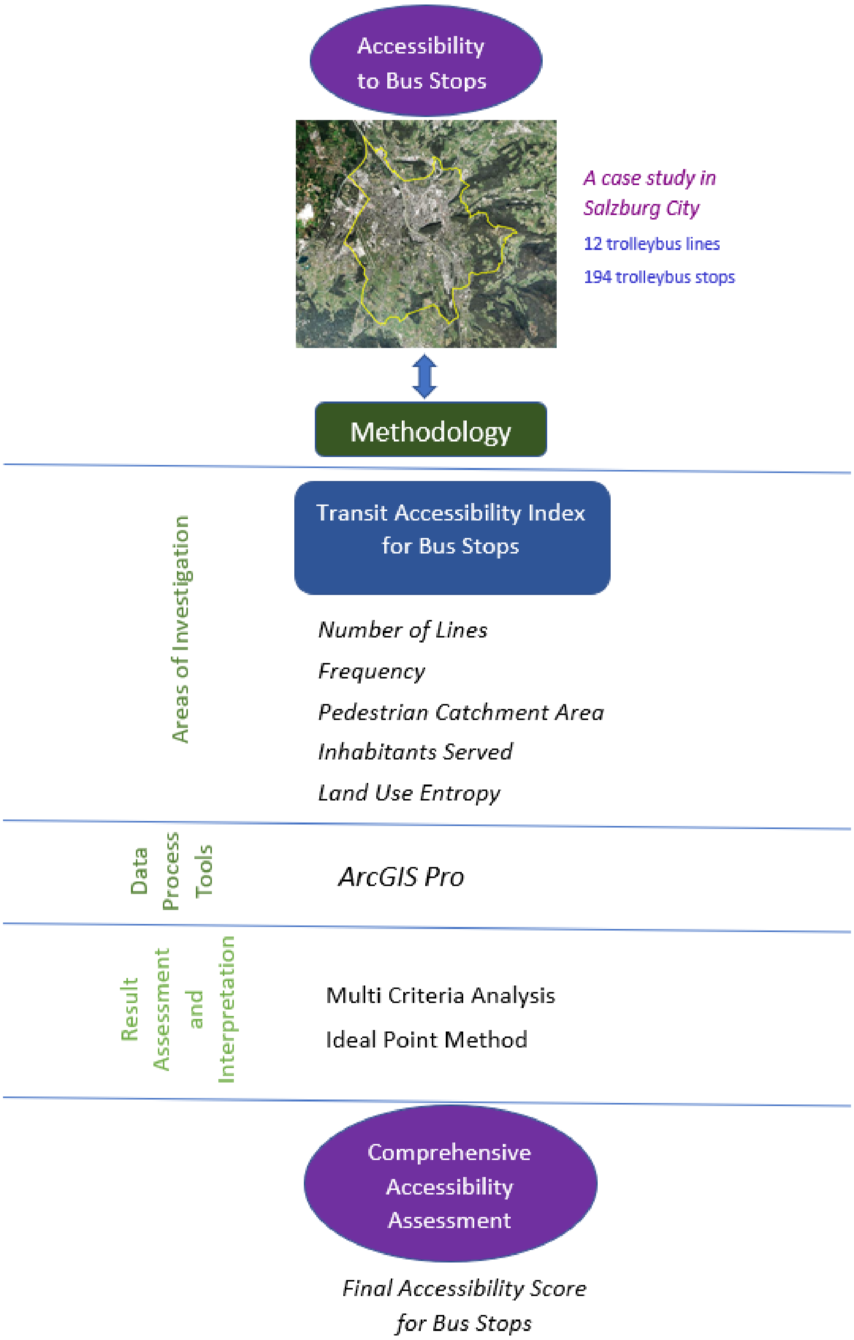


Figure 5: Methodology workflow

Transit Accessibility Index for Bus Stops

The process of choosing appropriate indicators to assess the accessibility of bus stops involves considering a range of evaluation categories such as transit service, built environment and bus stop quality. This approach aligns with the bus stop concept as a multi-faceted environment with diverse requirements. For this analysis, the accessibility to bus stops is calculated in terms of Transit Accessibility Index (TAI) which is assessed using five accessibility indicators. Such indicators are simple to calculate and can describe different performance levels for the bus stops.

Specific Indicators for the Transit Accessibility Index

a. Number of Lines

This indicates the total number of lines serving each of the public transport stops considered in the study area. This indicator is univocal and can be assessed directly from the secondary sources as well as from field survey. The number of lines is associated with the evaluation area transit service.

b. Frequency

Frequency is the total amount of vehicles arriving at or departing from each stop calculated on an hourly basis. This indicator is highly essential for evaluating the reliability, efficiency and quality of the bus stops. Frequency is also associated with the evaluation area transit service.

The calculation of the other indicators such as Pedestrian Catchment Area (PCA), Number of Inhabitants and Land Use Entropy (LUE) need some processing of the ground-based data. All of these indicators are associated with the evaluation area built environment. These indicators have been defined and utilized in various ways within both scientific and grey literature.

c. Pedestrian Catchment Area (PCA)

The pedestrian proximity to bus stops is determined using a widely recognized measure known as the PCA (Corazza & Favaretto, 2019). This measure quantifies the service area covered by pedestrians walking freely from each bus stop and is computed as either a circumference or Euclidean (straight-line) buffer. However, due to the potential overlap of Euclidean buffers and subsequent overestimation of the service area for a specific stop (Gutierrez & Garcia-Palomares, 2008), network buffers have been utilized as an alternative approach. Network-distance based service areas are calculated by determining the polygons that encompass edges within a 400-meter distance from the bus stop, using a dedicated GIS application known as the service area solver. The GIS application offers valuable visual data to evaluate the pedestrian-friendliness or hostility of a specific location.

d. Number of Inhabitants Served

The Number of Inhabitants Served is an indicator that uses PCA data to identify the total potential population as a generator or attractor of a given stop. The same service areas for PCA are associated, this time, to inhabitants according to population data. For the calculation of this indicator, the distribution of point population on 100 x 100 m grid is considered, for the inhabitants associated to a network-distance based service area from a given stop in the study area.

e. Land Use Entropy (LUE)

The idea of Land Use Entropy includes calculating the diversity of land use and assessing the stability of various land uses within a specified area. The level of homogeneity or heterogeneity in land use category can differ significantly from one place to another. According to the definition of LUE (Corazza & Favaretto, 2019) this indicator is calculated for each line starting from the percentage P_ij of i land use category in the j - study area as follows:

$$LUE = \frac{\sum_{i=1}^{n} P_{ij} \times \ln(P_{ij})}{\ln(N_j)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where,

P_{ij} = percentage of i land use category in j study area

N_j = number of land use categories in j study area

The diversity of land use is essential for the attraction and generation of various types of traffic and demand. This suggests that, in the context of bus services, a higher value of LUE in a specific area can enhance the attractiveness of the bus lines operating within that area. For this case study, LUE was calculated individually for each line that served the area. The LUE value assigned to each stop represents the average LUE values for each line that served that particular stop.

Once all the data have been collected and evaluated as specified above, a multi-criteria procedure is developed to calculate the final score that describes the accessibility to each bus stop by combining the values of all five indicators. For this purpose, the values of all the indicators need to be first converted to V_i in a 0 to 1 scale. This can be done by using the formula:

$$V_i = \frac{x_i - x_{min}}{x_{max} - x_{min}} \quad \dots\dots (2)$$

where,
x_i = value of indicator
x_{min} = minimum value of indicator
x_{max} = maximum value of indicator

These outcomes are further weighted by assigning the appropriate weights to each indicator. Given that the data is geospatially referenced, the Ideal Point Method (IPM) appears to be a suitable tool for conducting multi-criteria analysis. This approach offers one of the best solutions based on multiple criteria involved. The Ideal Point Method (IPM) is employed to rank the bus stops from best to worst in terms of their accessibility score. The weighting criteria for indicators is depicted in Table 1, which is based on the transit expert's assessment performed in a similar case study in Nomentano district in Italy.

Table 1: Ranking of indicators according to weights (Corazza and Favaretto, 2019)

Rank	Evaluation Category	Indicator	Weight
1	Transit Service	Frequency	0.32
2	Built Environment	No of Inhabitants served	0.20
3	Transit Service	Number of Lines	0.18
4	Built Environment	PCA	0.16
5	Built Environment	LUE	0.14

The procedure for calculating the final accessibility score is reiterated for all the bus stops in the study area. This leads to an overall accessibility assessment in which five performance categories are created, further classifying the bus stops into their respective categories based on the final accessibility score.

3. Results and Discussions

The following results are obtained from the calculation of the accessibility indicators. The statistical distribution of the values of accessibility indicators for all 194 bus stops in the study area are also depicted in the adjoining histograms.

3.1 Number of Lines

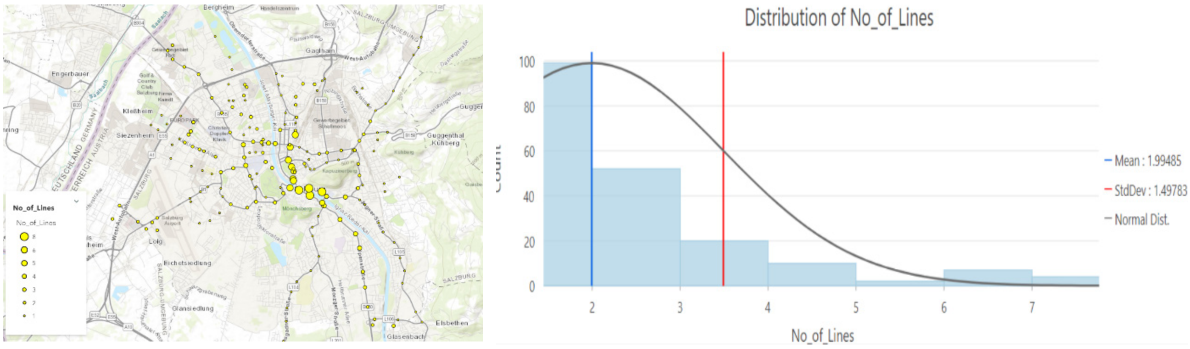


Figure 6 : Distribution of number of lines

From the distribution of the number of lines in Figure 6, it can be seen that more than 50% of the trolley bus stops are served by only one line. These stops are located mostly in the outskirts of the Salzburg city. The stops that are located in the core area of the city are served by up to 8 trolley bus lines.

3.2 Frequency

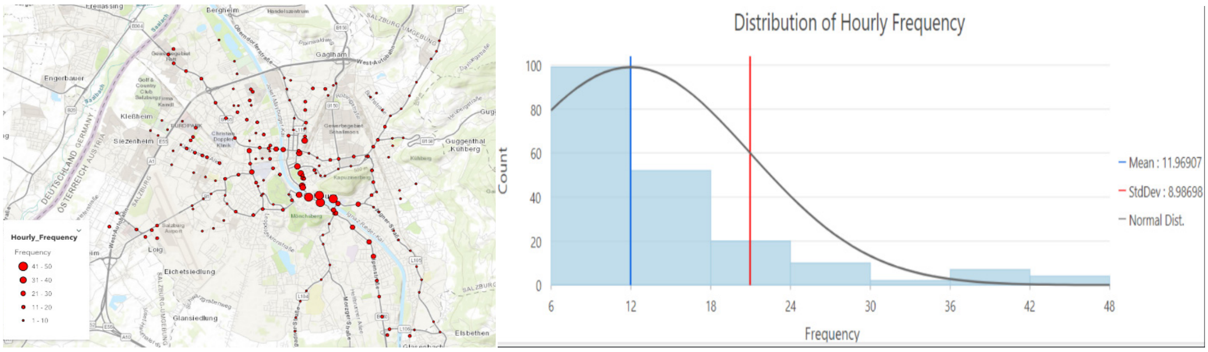


Figure 7: Distribution of frequency

Frequency is calculated on an hourly basis considering the case of a normal working day. Figure 7 shows that the stops in the core area of the city have a higher frequency of up to 48 vehicles per hour whereas the stops far from the central part of the city have a lower frequency of only 6 vehicles per hour.

3.3 Pedestrian Catchment Area (PCA)

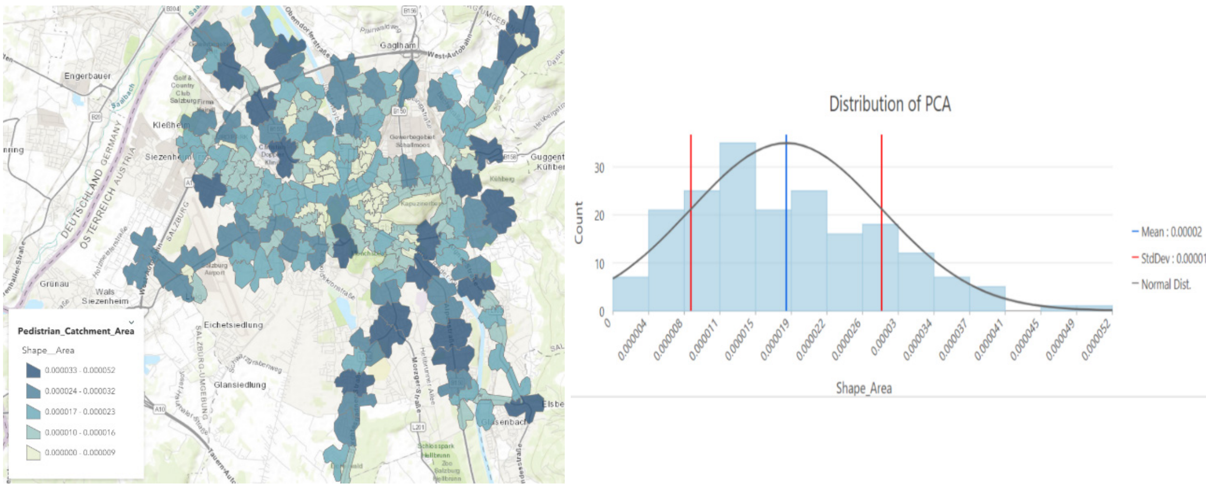


Figure 8: Pedestrian Catchment area (PCA)

The PCA is calculated using Network Analyst tool considering a walking distance of 400m from each bus stop. Figure 8 shows that the walkable area around the bus stops in the central part of the city are very less as compared to those in the outer part of the city.

3.4 Number of Inhabitants Served

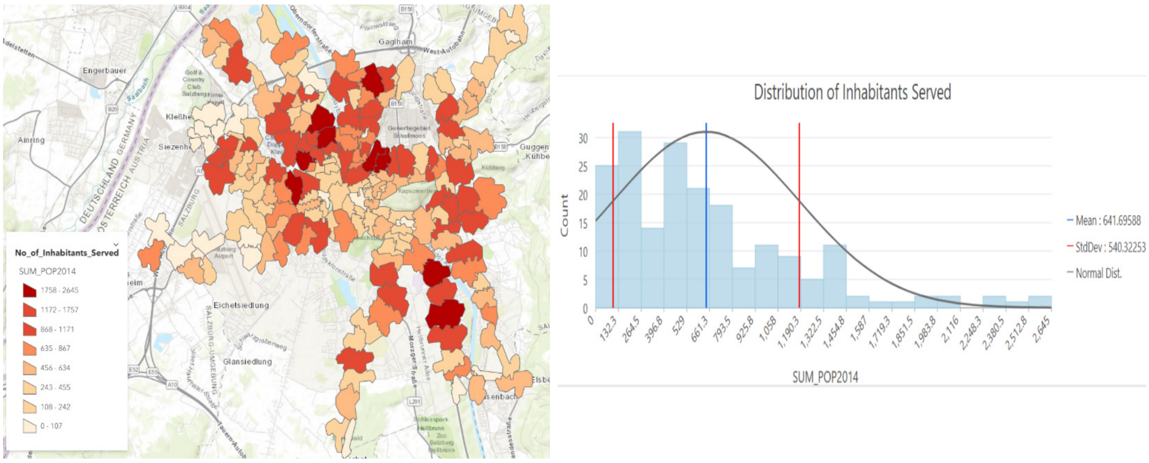


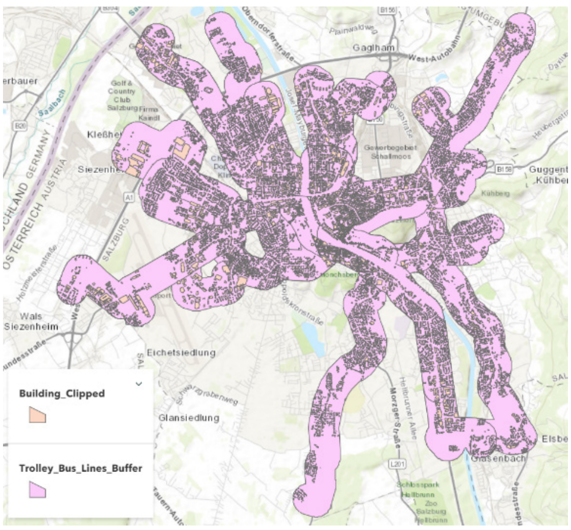
Figure 9: Number of inhabitants served

The number of inhabitants served is calculated as the sum of point population in the 400m catchment area for each bus stop. From Figure 9, it can be seen that the population distribution is non-uniform and ranges from 0 to a maximum of 2645 inhabitants living within a 400m walking distance from the stops.

3.5 Land Use Entropy (LUE)

The calculation of Land Use Entropy for the trolley bus stops is a multi-step process. Firstly, the building footprints within a buffer zone of 400m from the trolley bus lines are extracted. The extracted buildings are then classified into the following four categories and their percentage along each line is computed.

- Residential
- Public
- Commercial
- Industrial



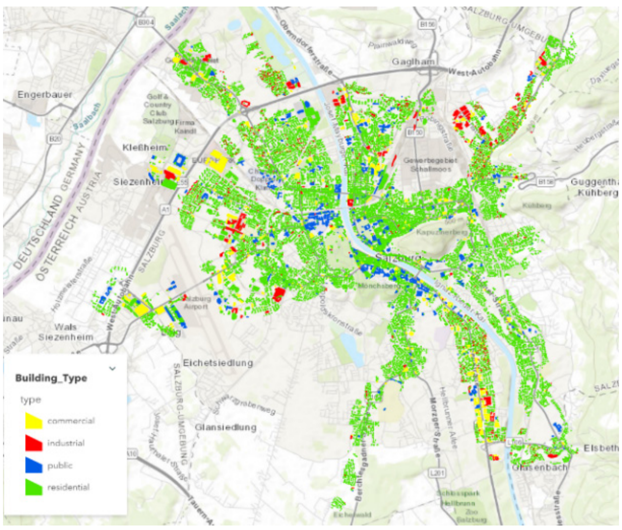


Figure 10: Buildings within 400m buffer

Figure 11: Building classification

The LUE for each line is first calculated using the aforementioned formula from the methodology section. Then the calculation of LUE for each stop is done by averaging the LUE value of each line serving the stops.

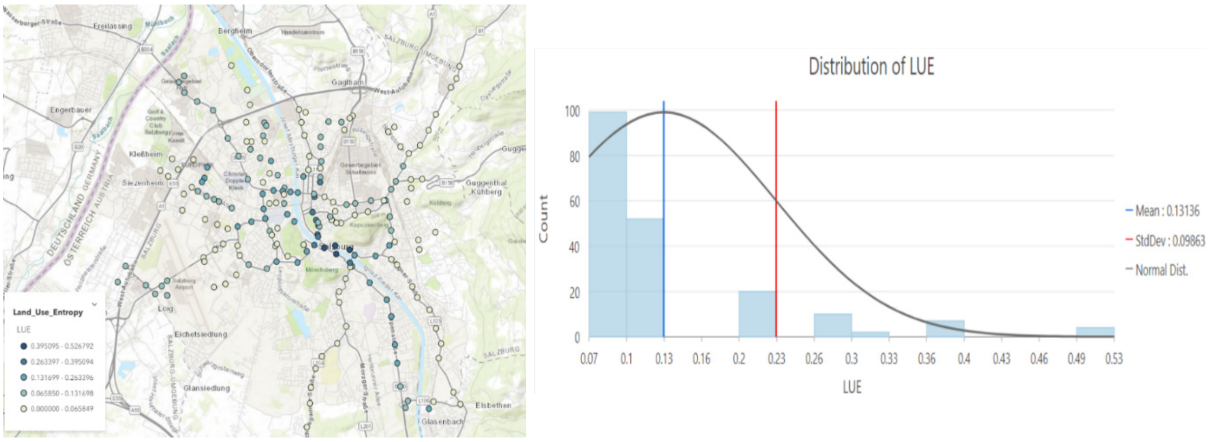


Figure 12: Land use entropy

From Figure 12, it can be seen that the bus stops with higher values of LUE are concentrated in the central part of the city which indicate the heterogeneity in the built-up type. The lower value of LUE towards the marginal stops indicates the dominance of a single built-up category in those regions. Table 2 summarizes the minimum, maximum and average values of each of the five accessibility indicators calculated for the bus stops.

Table 2: Minimum, maximum and average values of accessibility indicators

	Frequency	No of Inhabitants Served	Number of Lines	PCA	LUE
Maximum	48	2645	8	0.00005200	0.527
Minimum	6	0	1	0.00000015	0.066
Average	12	604	2	0.00001827	0.131

Calculation of Transit Accessibility Index (TAI)

The values of the five accessibility indicators for each of the bus stop are converted to a scale of 0 to 1. By assigning the respective weights to each indicator, the final accessibility score is calculated. As such, the score of “Ideal Bus Stop” always corresponds to 1 whereas that of the “Unideal Bus Stop” corresponds to 0.

Table 3 reports the accessibility score for the "Ideal Bus Stop", the real "Best Available Stop" and the "Worst Available Stop" in the study area. From the analysis, Rudolfskai is the most accessible stop with accessibility score of 0.654 while the least accessible stop is Fanny-von-Lehnert-Strasse with accessibility score of 0.017.

Table 3: Most accessible, least accessible and ideal bus stops

Indicator	Most Accessible (Rudolfskai)	Least Accessible (Fanny-von-Lehnert-Strasse)	Ideal Stop
Frequency	0.316	0.000	0.316
No. of Inhabitants served	0.036	0.001	0.203
Number of Lines	0.177	0.000	0.177

PCA	0.051	0.006	0.165
LUE	0.073	0.009	0.139
Total Score	**0.654**	**0.017**	**1.000**

The trolley bus stops can be further classified into five performance categories as shown in Figure 13 based on their final accessibility score. The red stops can be considered as totally accessible, orange stops as just accessible, yellow stops need to be improved, green stops need to be redesigned and the blue stops need to be relocated.

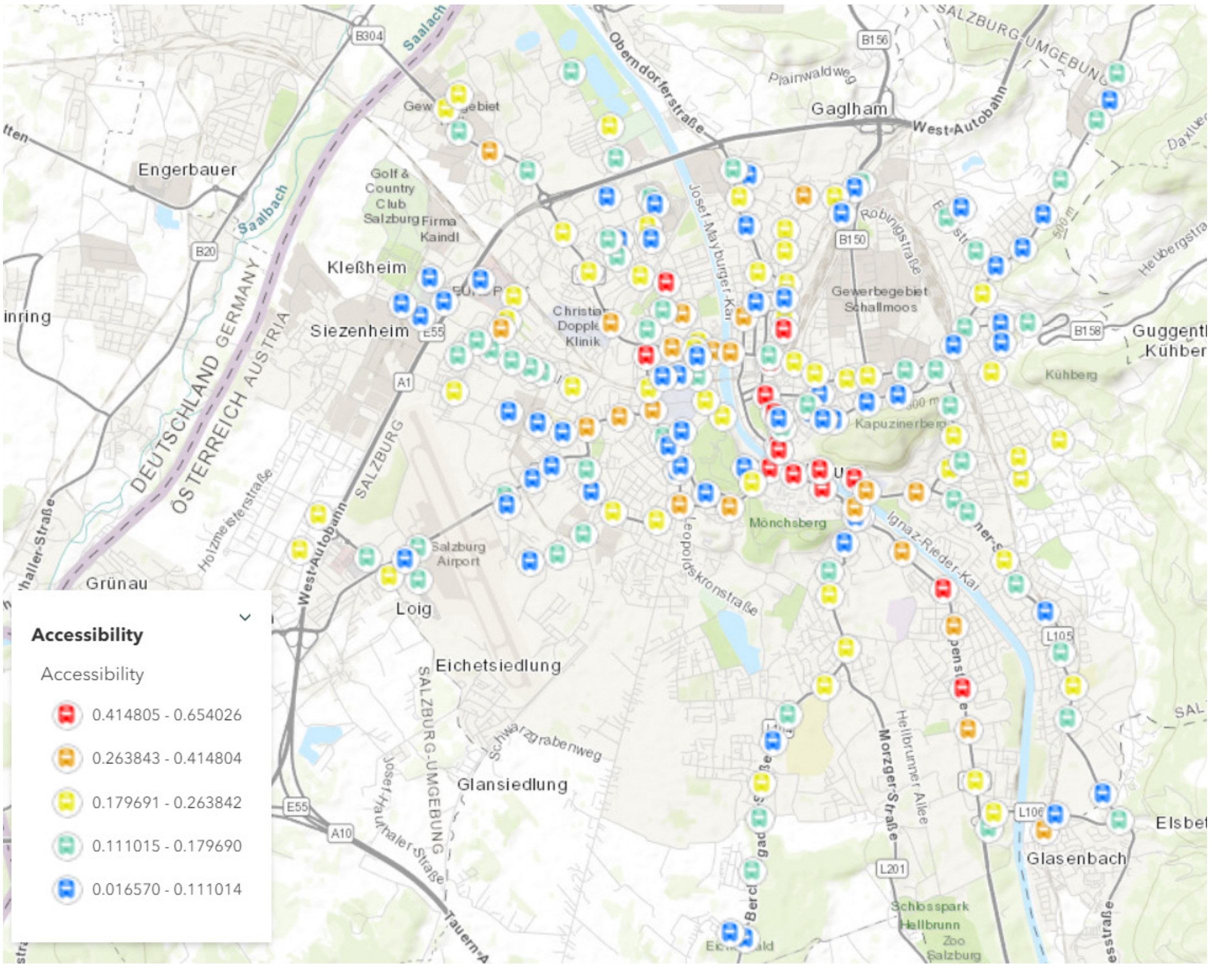


Figure 13: Accessibility of trolley bus stops in Salzburg City

4. Conclusions

The result from the analysis shows that the most accessible trolley bus stops are located in the core region of Salzburg city near to the city center and the main train station. This is evidenced by the higher values of accessibility indicators particularly the frequency and the number of lines. In general, higher the value of the accessibility indicators, higher is the Transit Accessibility Index (TAI) and hence more attractive is the facility.

The application of Ideal Point Method to determine the Transit Accessibility Index seems greatly suitable for evaluating the accessibility of the 194-trolley bus stops in the city of Salzburg. This has enabled further to analyze which facilities are more accessible, which are less or not, and thus the need for adjustments or re-examination. Such kind of analysis is crucial for sustainable transport planning and help to promote smart mobility and better habitability of the city. This approach can also be replicated to other regions or countries and can serve as a guideline for similar type of analyses.

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