Analysis of public transport (in)accessibility and land-use pattern in different areas in Singapore

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Abstract. As more and more people continue to live in highly urbanised areas across the globe, reliable accessibility to amenities and services plays a vital role in sustainable development. One of the challenges in addressing this issue is the consistent and equal provision of public services, including transport for residents across the urban system. In this study, using a novel computational method combining geometrical analysis and information-theoretic measures, we analyse the accessibility to public transport in terms of the spatial coverage of the transport nodes (stops) and the quality of service at these nodes across different areas. Furthermore, using a network clustering procedure, we also characterise the land-use pattern of those areas and relate that to their public transport accessibility. Using Singapore as a case study, we find that the commercial areas in its central business district expectedly have excellent accessibility and the residential areas also have good to very good accessibility. However, not every residential area is equally accessible. While the spatial coverage of stops in these areas is very good, the quality of service indicates substantial variation among different regions, with high contrast between the central and eastern areas compared to the others in the west and north of the city-state. We believe this kind of analysis could yield a good understanding of the current level of public transport services across the urban system, and their disparity will provide valuable and actionable insights into future development plans.

Keywords: Public transport · Land use · Spatial pattern · Entropy · GIS · Singapore.

1   Introduction

With countries having pledged to reach net-zero emissions in the next few decades [1], plans are being put together by governments around the world to achieve the goal. Among the courses of action, a feasible way to accomplish this is to reduce the use of private vehicles and shift toward the more sustainable use of public transit. As part of the process, improving the quality and accessibility of existing public transport infrastructure is vital in achieving high ridership. Furthermore, from a social perspective, equal public transport service provision also contributes to sustainable development in urban areas [12, 14].

Public transport accessibility has received much attention from various communities. Among the measures of accessibility, the public transport accessibility level (PTAL) [15], which combines the walking distance to the transport nodes and the frequency of the services, has been frequently used for its simple calculation. However, the method's main disadvantage lies in using a heuristic distance threshold from a point of interest to its nearby transport nodes, which may produce artefacts in certain areas. More sophisticated methods have been proposed, such as analysing the walking distance and time to the nearest bus stop using the actual walking paths [8]. Yet, the approach may not be suitable for large-scale analysis where the amount of spatial data required would make the procedure computationally inefficient. Other authors have also looked at the optimal spacing of bus stops [13] so that the system's overall performance could be improved and the link with land use could be established [2, 10].

While public transport accessibility is intuitively about the ability and ease of users to reach their destination, it could also be examined from the opposite perspective of inaccessibility, which could be imagined to hold the hidden information about the system. Along that line, in this study, we formulate the study of public transport accessibility as an inverse problem, that is, to view the spatial inaccessible area as "conjugate" of its accessible counterpart. This approach has received relatively little attention in the literature, but it can be shown to provide interesting insights into the spatial organisation of an urban system. Using this approach, we will explore the public transport accessibility of different areas in terms of the bus stops' spatial (non-)coverage and their associated quality of service. The methodology will be demonstrated in the city-state of Singapore, and the accessibility of its different areas will be analysed.

In the Singapore context, several studies have been performed to analyse the accessibility to the Mass Rapid Transit (MRT) stations [11, 17, 18] or the impact of the expansion of the MRT network on accessibility to employment [3]. Yet, few have been done for the bus network. Therefore, this work also contributes to discerning the accessibility of bus services in Singapore. While a public transport system typically contains train and bus services, it could be argued that analysing the public bus network alone is sufficient in terms of the spatial accessibility of different local areas. This is because bus stops are also well presented at the train stations, and the bus network has a high degree of penetration into the residential areas.

2   Data and methods

Data. For this study, the **public transport** data in Singapore is obtained from the Land Transport Authority (LTA) [9] and includes the information on the bus stops and the services serving those bus stops. For every bus stop, we filter the data to select only the regular services, i.e. available throughout the day with the lowest dispatch frequency not longer than 30 minutes. On the other hand, the **land-use** data is obtained from the Urban Redevelopment Authority (URA) through the Singapore's open data portal [16], comprising 33 land-use

types, ranging from commercial, residential to industrial use. We exclude the areas being used for ports or airports as they are generally not accessible to the public, leaving the remaining 32 types in the analysis. Similarly, the **planning area** data is also available from the same portal. There are 55 planning areas in Singapore and they will serve as the spatial unit of analysis in this study in terms of both public transport accessibility and land-use patterns.

Analysis of land-use pattern. In this study, we characterise each planning area by the types of land use that make up its area. Specifically, the land-use profile of a planning area can be presented as a 32-dimensional vector $\boldsymbol{p} = (p_1, p_2, \ldots, p_{32})$ with p_i being the percentage of each land-use type within the planning area. After that, we employ cosine similarity to measure how close a pair of vectors are to one another or how similar the two corresponding planning areas are. The similarity score ranges between 0 (totally different) and 1 (perfectly identical). After measuring the similarity between the land-use configuration of the planning areas, a network can be constructed by treating each area as a node and adding a link between a pair of planning areas if their similarity score is above 0.7 (corresponding to an angle of 45 degrees, which geometrically suggests some degree of similarity). The planning area network will be analysed using the clustering procedure as described in [7] to identify the groups of planning areas that are most similar to one another and classify them. The results of land-use classification will form the basis for selecting planning areas for the subsequent analysis of public transport accessibility (see Sec. 3).

Analysis of public transport nodes. A place of interest is said to have good access to public transport if its distance to the nearest public transport node (bus stop) is reasonably short. Using this picture, we can identify the so-called "non-covered" area at a given distance ρ, or the area that is outside (all) the circles of radius ρ centred at the bus stops. For a suitable value of ρ, if the area covered by the buffer circles is considered the accessible area, we can call the area that is not covered by any of the circles the inaccessible one.

To determine the suitable value of ρ, we can look at the spatial structure of the patches formed in the process of identifying the non-covered area. As the value of ρ increases from 0, the non-covered area transits from a connected land mass to vanishing isolates when most of the area is covered at a large value of ρ. In between, we can observe that the non-covered area becomes highly fragmented at some intermediate value of ρ. Using the information-theoretic measure of entropy, we can quantify the degree of fragmentation of the non-covered patches. This is similar to the idea of measuring the complexity of a spatial point pattern [5] that has been applied to study the relative location of public transport nodes in the urban context [4, 6]. The entropy measure peaks at some intermediate value of ρ, called the critical distance, at which the inaccessible space is most fragmented, marking the onset of accessibility. Subsequently, we can use this critical distance to assess the spatial coverage of public transport nodes across different planning areas in Singapore.
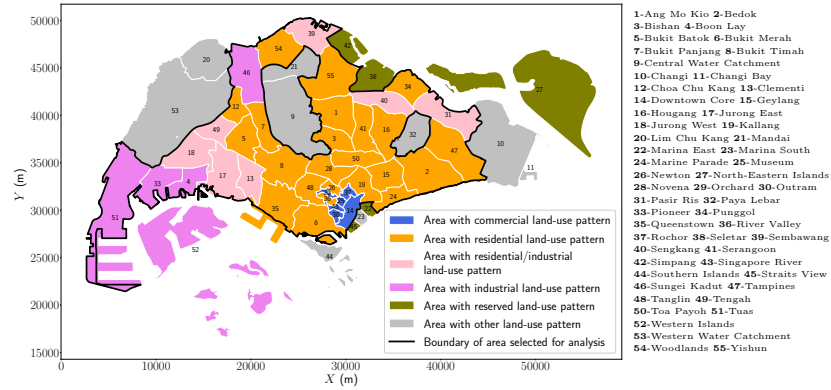
Fig. 1. Classification of planning areas based on composition of land-use types.

3   Results and discussion

Classification of areas based on land-use pattern. While different urban areas typically contain complex land-use patterns, they can generally be clustered into a small number of groups using the procedure described in Sec. 2. The 55 planning areas (PAs) in Singapore can be grouped into six major categories (see Fig. 1), namely commercial, residential, residential mixed with industrial, industrial, reserved, and others, based on their composition of the 32 land-use types [16]. The first group comprises 6 PAs with a very high proportion of land for commercial and hotel usage. These areas are indeed in Singapore's Central Business District (CBD), and we label them as "commercial" land-use pattern. The second group contains 23 PAs with predominantly land use of residential type and, hence, is labelled as "residential". The third group includes 7 PAs, which have a high proportion of land for both residential use and business 2 (clean, light industry and general industry or warehouse). These areas suggest the co-location of residential development alongside the industrial facilities and are labelled as "residential/industrial". The fourth group contains 5 PAs with land chiefly for business 2 and, hence, is labelled as "industrial". The fifth group has 5 PAs with land use mainly of reserved type and, hence, is labelled as "reserved". The final group contains 9 PAs with very distinct land-use profiles from the rest of the areas and, thus, is labelled as "others".

For subsequent analysis, we decided to exclude the 5 areas with "reserved" land-use pattern as they are reserved by the government for future development and currently do not accommodate any urban activities. The 9 "other" areas are also excluded as they do not reflect the typical urban characteristics in Singapore. Furthermore, we also exclude the area of Western Islands (labelled 52 in Fig. 1) as they are not served by public transport in Singapore. Altogether, we only retain 40 areas for the analysis of public transport accessibility. The final selection of areas for analysis is shown with a thick black boundary in Fig. 1 (without the ports and airports, which have earlier been excluded).
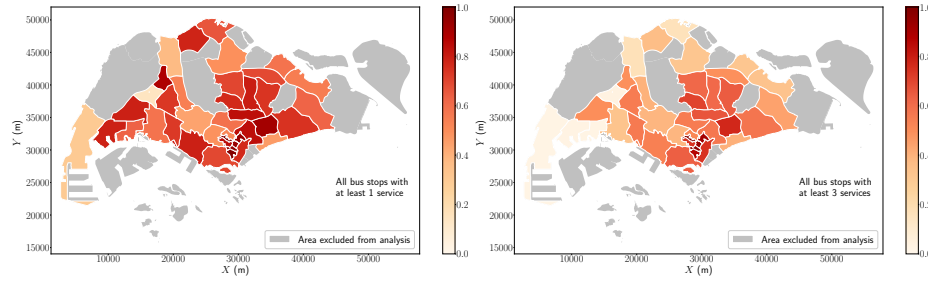
Fig. 2. Spatial coverage of bus stops at the critical distance of 240 m across Singapore.

Measure of accessibility to public transport nodes. The analysis of the fragmentation of the non-covered patches in Sec. 2 reveals a critical distance at which the inaccessible space is most fragmented, signifying a transition of state [5]. In Singapore, this critical value is found to be 240 m and agrees reasonably well with the perception of the typical distance that most people would find comfortable for walking (3 to 4 minutes). This might reflect the result of the transport planning that in most areas, people would walk no more than 240 m to reach the nearest bus stops. While this value reflects an overall good spatial coverage of bus stops across Singapore, we can also utilise it to analyse and assess the public transport accessibility of different areas in the city-state.

Using the buffer distance of 240 m, we identify the area covered by the bus stops served by at least a regular bus service in Singapore, or the "accessible area". We compute the total (union) accessible area within each PA as a fraction of its total area. The result of such measure over all selected PAs is shown as a choropleth map in Fig. 2. It could be observed that most of the PAs selected for analysis have very good spatial coverage of the public transport nodes. Notably, the CBD has excellent coverage when the PAs it contains are almost entirely covered by the bus stops at 240 m. Outside the city centre, the majority of the PAs of the residential type also have a high quality of bus stop coverage. The PAs with a mixture of residential and industrial land use generally have fair coverage. The remaining industrial-type areas typically have low spatial coverage.

As argued earlier, spatial coverage is only part of the measure of the accessibility of public transport in an area. Besides the spatial coverage, the quality of service at the bus stops also contributes significantly to accessibility. Bus stops served by more services are arguably more "accessible" as they provide travel options to more places. To probe the service quality, we look at the spatial coverage of bus stops served by at least 3 regular services, using the same buffer distance of 240 m. The map in Fig. 2 shows that the CBD still enjoys an excellent coverage of stops with at least 3 services. However, the quality of the coverage starts to decline outside the CBD. Yet, the decline takes different rates in different regions, with many areas having poorer coverage than others. Across Singapore, the central and eastern parts appear to have much better accessibility than the city-state's western and northern parts.

Discussion. It should be noted that the method of geometrical analysis described in this work can also shed light on the spatial structure of an area. For example, the high fraction of area covered by the bus stops at a certain buffer radius can be related to the compactness of an area, reflecting the high density of bus stops within a small area, like the case of the planning areas in the CBD of Singapore. On the other hand, the concept of the critical distance allows us to gain insight into the sparseness of the (location of the) bus stops, which in most cases reflects the level of development [6].

The result of the spatial coverage in Fig. 2 could highlight the difference in the quality of accessibility across different areas in the same city, which might otherwise not be apparent. In the Singapore context, the results suggest that the new towns of Punggol and Sembawang still need much improvement in transport planning, whereas middle-aged towns like Jurong East still have a lot of potential for further development. In contrast, the areas with a high density of private housing like Bukit Timah or Marine Parade, despite having only average spatial coverage of the bus stops, appear to have a good quality of the services provided. While it is commonly understood that the residents in those areas belong to the higher income group and have a high rate of ownership of private vehicles, improving public transport accessibility in terms of shorter walking distance to bus stops could nudge their transport behaviour toward a more sustainable one.

4   Conclusion

In this study, we develop a computational method to analyse the quality of public transport accessibility in relation to the pattern of land use in different urban areas and apply it to the case study of the city-state of Singapore. The method combines geometrical analysis and information-theoretic measures to quantify the area that is not within a certain buffer distance of the public transport nodes, called the non-covered or inaccessible area. It is argued that the spatial structure of such inaccessible area undergoes a phase transition with the entropy measure maximising at some critical value of the buffer distance. This critical value of the buffer distance is where the inaccessible area is most fragmented, marking the onset of accessibility within the system. In Singapore, this distance is about 240 m, indicating an overall high density of bus stops. However, analysis at the individual area level reveals that despite having good spatial coverage of the bus stops, the quality of the service at these stops varies across the country.

On the other hand, we also analyse the pattern of land use in these areas and relate it to the public transport accessibility, providing more context for its interpretation. Typically, the commercial and residential areas of the city-state are found with very good accessibility. However, residential areas in different parts of the country exhibit marked differences, with much better accessibility in the central and eastern regions than in the west and north of Singapore. The results obtained from this research can be useful for the relevant urban and transport planning authorities in further developing the public transport network. For example, the results could help identify areas where improvements are

needed and devise policies to nudge people's behaviour toward more sustainable public transport usage.

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