Transit-Ability: An Interactive Shiny App Analysing the Accessibility of Singapore's Rail Transport System

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ABSTRACT

Geographical accessibility refers to the ease of reaching a location from other locations. Accessibility helps policy makers in understanding and modeling transportation interactions and assessing the effectiveness of transport systems and their objectives. There are various methods that allow us to study the accessibility of locations to each other. In this paper, we will be focusing on three models to analyse accessibility of the Singapore Mass Rapid Transit (MRT) System via an Interactive R Shiny Application. These models are (1) Hansen Method, (2) Kernel Density Two-Step Floating Catchment Area (KD2SFCA) and (3) Spatial Accessibility Model (SAM).

With the huge amount of financing that is being poured into Singapore's transport system, we want to use these models to evaluate the effectiveness of these train stations in serving Singaporeans. We built an interactive application that is made public to allow Singaporeans and researchers who do not have the knowledge of programming and geographic models to perform their own analysis. With just a few clicks and tweaks, they are able to customise the model according to what they wish to find out. This paper will elaborate on the motivation of our research implementation, approach, interface design of the application and future direction of the application.

KEYWORDS

R, R Shiny, Accessibility analysis, Accessibility measures, Hansen, Kernel Density Two-Step Floating Catchment Area, Spatial Accessibility Model

1 INTRODUCTION

1.1 Motivation

The first Mass Rapid Transit (MRT) system lines were officially launched in 1988, with the aim of reducing traffic congestion on the roads to cope with the increasing population.

In 2020, Singapore's Transport Minister Khaw Boon Wan announced that more than $60 billion will be invested to expand the country's rail system over the next 10 years [1]. With this shocking amount, it is no wonder that Singapore is ranked fourth in the world for urban mobility readiness [2].

Accessibility plays an important role in how we travel within our city. It helps transport experts decide on how the transport network will be shaped. The current outlook for Singapore's public transport is to hit 75% utility of mass public transports during peak periods and an average of 45 minutes travel time for 90% of peak period journeys by 2040 [3]. This, however, can only be made possible with extensive planning and research as it is not easy to identify population groups that benefit the most from accessibility given the various metrics of calculations and definitions which give rise to different conclusions. For example, we cannot merely consider distance as a measure of accessibility. Other metrics like congestion, capacity usage ratio, passenger kilometers and social and economic opportunities also come into play when considering accessibility. If not well planned, negative impacts on mobility can arise.

The large amount of financing being poured into the building of Singapore's rail system coupled with the introduction of three new MRT lines across the country in the next 10 years [4] makes it important for policy makers and researchers to understand if these new stations are effective in serving Singaporeans. Should these stations not be useful for the citizens in bringing them to places, it will only present a negative ROI in terms of financial and possible environmental impacts.

With various kinds of accessibility measures, it is important to choose the most appropriate model to calculate travel impedance. The team looked through various models which will be explored in section 2 of this paper. Ultimately, the Hansen Method, KD2SFCA and SAM were selected as the models for our analysis.

In view of the importance of understanding accessibility of train stations, the team was motivated to develop a web-based geospatial application that equipped Singaporeans and researchers with the ability to perform their own analysis using different models on the accessibility of stations from places of interest like hawker centres, supermarkets, shopping malls, kindergartens, childcare centres, primary schools, parks, tourist attractions and eldercare centres. They should be able to come up with their own conclusions even without programming knowledge.

1.2 Objectives

This research attempts to achieve the following objectives:

1. Find out the accessibility of MRT and LRT stations for commuters in Singapore.
2. Find out which MRT and LRT station is the most accessible/inaccessible.
3. Find out how well the coverage of the rail transport system is.
4. Visualise how the locations of MRT and LRT stations are related with its surrounding locations e.g., schools, parks shopping malls etc.

We also aim to develop the application in a user-friendly manner so that the common man will be able to perform their analysis with ease.

2 LITERATURE REVIEW

2.1 Raster and Network-Based Methods in Measuring Geographic Accessibility

In search of other methods to measure geographic accessibility, the research of accessibility to healthcare facilities by Delamater et el. defined geographic accessibility as a measure of travel time [5]. They explained raster and network-based models of spatial data representation, which are often used to estimate travel time, also used by Google Maps to estimate travel time. Early studies acknowledged that the travel costs among locations were more complex than those provided by straight-line (Euclidean) distance measures. It argues that the Euclidean travel distance does not consider speed limit or travel speeds.

In the network model, travel time is calculated using edge distances and travel speeds. Road segments are edges that are connected at road intersections, nodes. However, because it doesn't represent areal extents, the raster data model is introduced where a series of regularly sized cells are arranged in a lattice. Thus, locations can be represented with their two-dimensional coordinates. This makes it attractive to create service areas. From here, our team got a rough gauge of the importance of having regular shaped geometries as the base.

Delamater et el. also emphasised on the importance of considering the different road situations for example, time delays when making turns. Because this paper focuses on train accessibility to places of interest that are within walking distance, an equivalent to a time delay could be when a pedestrian is waiting to cross the road at a red light.

2.2 Analysis of Impact of the MRT System on Accessibility in Singapore Using a GIS Tool

This paper by Zhu and Liu studied the difference in accessibility before and after the Changi Airport MRT extension and the North-East line were introduced, by using an integrated Geographic Information Systems tool via the ArcView software.

The measures of accessibility discussed in the paper include having individual destinations being weighted by their attractiveness or socio-economic factors like number of residents, social and age class. These factors are said to reflect the level of potential demand of the destinations [6].

All in all, their accessibility tool included various models that took in a plethora of considerations for example, using travel cost in terms of adult fares for taking the LRT and MRT to find out accessibility to commercial opportunities via the *Network Cost Matrix* function and working population per subzone to identify accessibility to working population from HDBs via potential models [7, 8].

The authors created their geographic tool with the following ideation flow:

1. Concept Formulation – Consisting of problem definition and data collection.
2. Measure Selection and Specification – Decides on the appropriate accessibility measures e.g., attractiveness of a location, or socio-economic factors.
3. Accessibility Measurement – The process of calculating the accessibility values based on the selected measures.
4. Interpretation and Evaluation – To visualise the accessibility values in 3D maps, isolines, tables and charts.

Users can conduct their own analysis according to the above flow with the help of the tool and are able to select the different methods they want to explore.

Based on the paper and GIS tool created by Zhu and Liu, our team decided to investigate using the combination of different types of distance matrix coupled with capacity and demand to represent capacity of the place of interest and demand of the MRT station, while providing users with the ability to change these parameters accordingly to their preferences.

2.3 Geographic Analysis of Singapore MRT

This project by Hsu explored (1) the relationship between population density and MRT locations and (2) the number of people who took the MRT based on planning zones.

Hsu mentioned a few challenges faced during the process of achieving his objectives. These challenges included:

1. Data pre-processing and joining of data takes a long time as different datasets contain different information. The act of going through individual files to understand which field they should be joined on was tedious.
2. Visualising the results led to a cluttered view on a single map.

In light of this, the team had prepared for these scenarios and started working on building the tool earlier to ensure that there was sufficient time to build a user-friendly interface that made analysis easy for users to understand. Most importantly, allowing the user to have a good User Experience for easy understanding and navigation around the application.

3 ANALYSIS METHOD

3.1 Datasets and Preparation

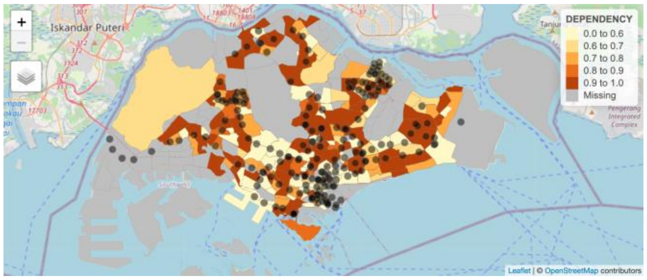

Figure 1: Population Density Map with MRT Stations

In order to study the accessibility of the rail system in Singapore, the team obtain Singapore's national boundary, planning areas, population density, MRT lines, MRT and LRT stations. We visualised population density on the different planning zones as polygons, and MRT stations as points in a choropleth map (Figure 1).

However, irregularly shaped polygons are created arbitrarily which renders the calculation of accessibility inaccurate. With the help of Dr Kam Tin Seong, the team used hexagons as the geographical unit. Each hexagon represents a 250m width and reduces the sampling bias from the edge effects, as it has a low perimeter-to-area ratio [9].

In addition, we identified places that we want to map to the stations to measure accessibility like hawker centres, supermarkets, shopping malls, kindergartens, childcare centres, primary schools, parks, tourist attractions and eldercare centres. All datasets were taken from official government repositories like LTA's data mall and data.gov.sg.

Aspatial data that are in .csv format have to be converted to sf dataframes using the *st_as_sf()* function. After which, converting all aspatial data to their appropriate coordinate systems and EPSG codes in place, *st_transform (crs = 3414)*. The team checked for missing value using *dataset[rowSums(is.na(dataset))!=0,]* and whether the geometries are valid using *st_is_valid(dataset)*.

3.2 Accessibility Models

After data pre-processing, the data was fed into the different models namely Hansen Model, KD2SFCA and SAM. The decision to show three different models lets users know that there are various ways of calculating accessibility. Below explains each model.

3.2.1 Hansen Method. The Hansen Method involves using GIS to analyze the spatial relationship between transportation infrastructure and population utility. It calculates the travel time between each point in the study area and the nearest transportation facility to create maps that show the level of accessibility to different types of transportation for each location. This method is useful in identifying areas that are underserved by transportation infrastructure and evaluating the potential impacts of new transportation investments, helping planners and policy makers make more informed decisions about transportation investments and ensuring that transportation services are distributed fairly.

3.3.2 KD2SFCA. The KD2SFCA method adopts a distance decay rule to analyze the spatial relationship between train stations and population. The method calculates the number of train stations within a certain travel time of each place of interest and vice versa, taking into account both supply and demand of the train stations. This results in a series of maps that show the level of train stations' accessibility for each location in the study area. This method is useful in identifying areas with poor accessibility to stations. In this project, demand will depend on the population at each place of interest to identify how accessible train stations are to those places. However for this project, we assume that the demand and capacity of the places of interest are the same due to the limited time frame of the project.

3.3.3 SAM. The Spatial Accessibility Measure (SAM) involves using GIS to analyze the spatial relationship between a service facility and a population. The method calculates the level of accessibility to the service facility for each location in the study area, considering factors such as travel time and distance, mode of transportation, population weighting. The result is a series of maps that show the level of accessibility for each location, which can be used to identify areas that are underserved by the service facility. This method is useful in informing policy and planning decisions related to service provision and can be applied to a range of service types, including healthcare, education, and retail.

4 DESIGN FRAMEWORK

The application, Transit-Ability, was designed according to Schneiderman's mantra [10]: Overview first, zoom and filter, details on demand. It consists of 3 views namely: Overview, EDA and tabs for the different methods used to calculate accessibility.

Figure 2: Overview Screen of Application

The first page follows the principle "Overview" where we provide the user with a summary of what the application is about and links to the datasets we used for the analysis (Figure 2). The user can then zoom in to the different methods implemented to analyse the results by navigating between the relevant tabs on the top ribbon of the application.

Figure 3: Control Panel

We have a consistent design for each tab of the application, where the control panel allows users to select the analysis methods according to their own needs (Figure 3). They have the option of filtering the datasets of places of interests, region of Singapore (e.g., North, Central, East, North-East, West) and colour schemes with drop-down lists.

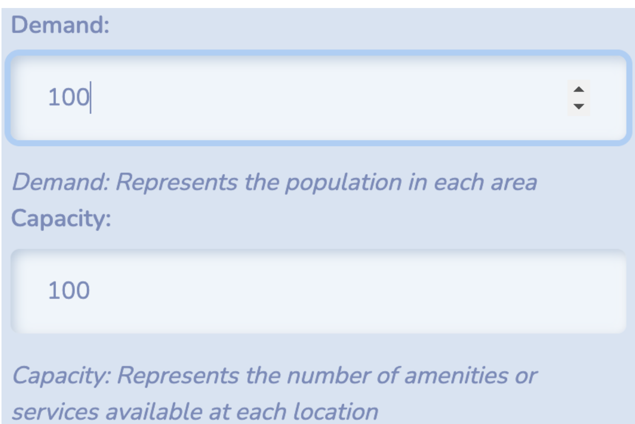

Figure 4: Input Field for Specifying Demand and Capacity

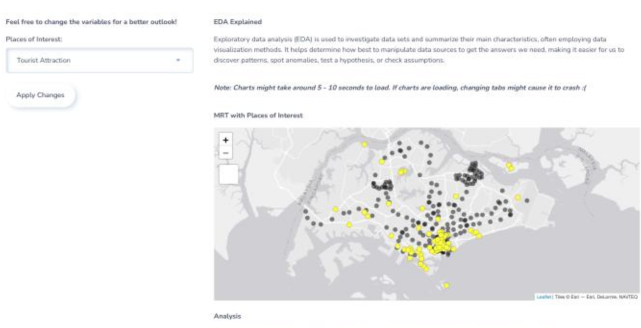

Figure 5: Graphs and Explanations Populated on the Right

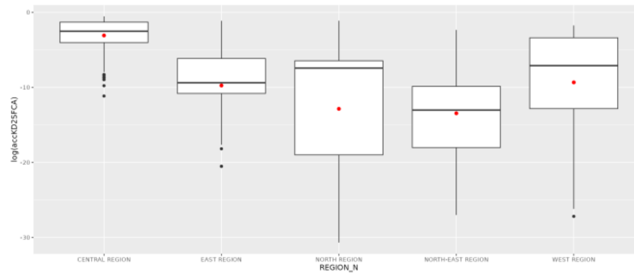

Figure 6: Statistical Box Plot

They can also adjust the demand and supply of train stations by inputting numeric digits (Figure 4). Once these parameters are set, they will be populated into the model and the results will be presented on the right of the screen as maps and statistical box plot with explanations for the user (Figure 5, Figure 6).

5 DEMONSTRATION

Our use case explores the accessibility of train stations to places of interest.

5.1 Use Case 1: EDA

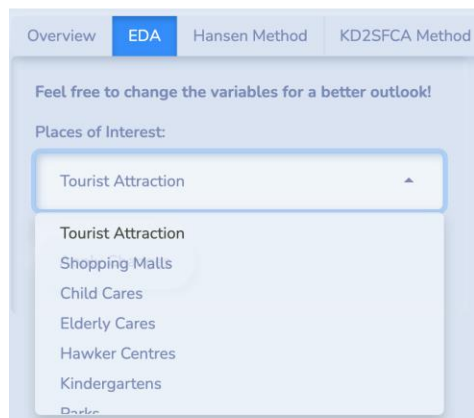

Figure 7: Left Panel of Drop-Down List to Select Place of Interest

Figure 8: Map Highlighting Place of Interest and MRT Stations

Before performing analysis on accessibility, users are recommended to get an overview of the locations of the place of interest. They can select a place of interest from the left panel (Figure 7) and a map displaying the locations of the place of interest and MRT stations will be loaded on the right (Figure 8).

5.2 Use Case 2: Accessibility of MRT to Tourist Attractions using Hansen Method

5.2.1 Model Analysis. The grey points on the map in Figure 9 represent the locations of tourist attractions while the black points represent MRT stations. Measuring accessibility with the Hansen Method tells us that MRT stations are very accessible to tourist attractions with values going up to 1517.

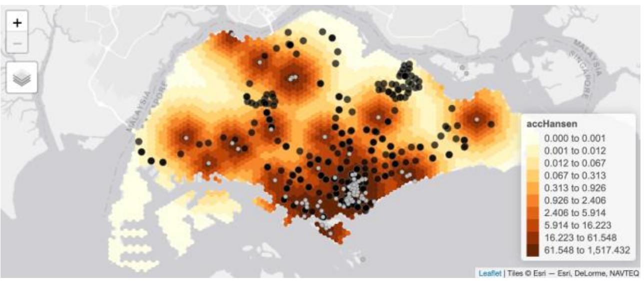

Figure 9: Hansen Map with Default Settings

5.2.2 Statistical Box Plot.

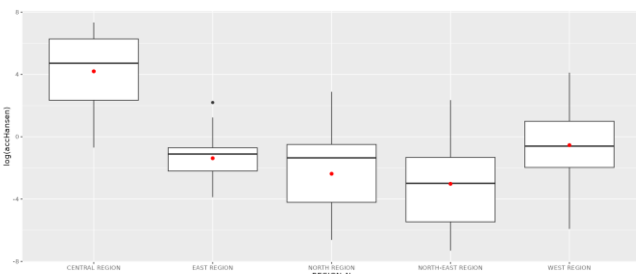

Figure 10: Box Plot for All Regions with Hansen Method

The box plot in Figure 10 shows that all MRT stations in the different regions are accessible from tourist attractions (Red Dot) as they are all within the upper and lower quartile. This provides users with a much clearer interpretation of the hexagon map in Figure 9.

5.3 Use Case 3: Accessibility of MRT to Tourist Attractions using KD2SFCA Method

5.3.1 Model Analysis. To look at accessibility from another viewpoint, the user can switch to the KD2SFCA tab where the default place of interest is set to 'Tourist Attractions'.

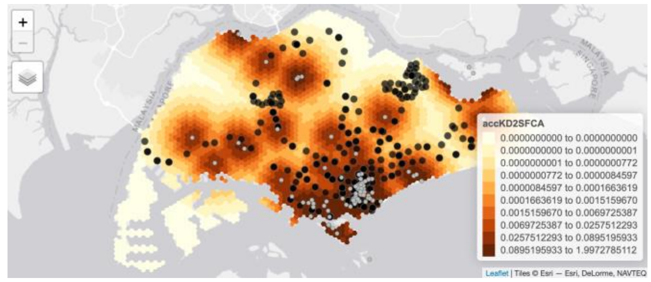

Figure 11: KD2SFCA Map with Default Settings

For KD2SFCA, both the demand and capacity are set to 100. We can see from Figure 11 that the North-East region is also highlighted in a darker shade indicating a higher accessibility as compared to the Hansen method where the same region is lighter in Figure 9. KD2SFCA also returns a much lower accessibility value overall as compared to Hansen's calculation.

5.3.2 Varying Demand. In the case where the user wants to perform an analysis on how accessibility changes if there is a higher demand for MRT stations, they can input the demand to be a higher number, for example 600.

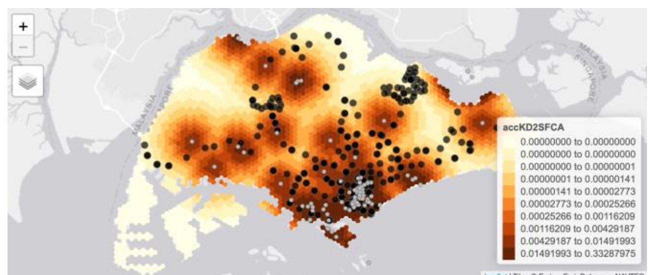

Figure 12: KD2SFCA Map with Demand Set to 600

In Figure 12 above, even though the heatmap of hexagons looks similar, the accessibility values are much smaller when demand is higher. This shows that accessibility decreases when the demand is higher than the available capacity (e.g., Figure 11)

5.4 Use Case 4: Accessibility of MRT to Tourist Attractions using SAM

5.4.1 Model Analysis. Switching to the tab on SAM, the graphs generated are also set to the default settings.

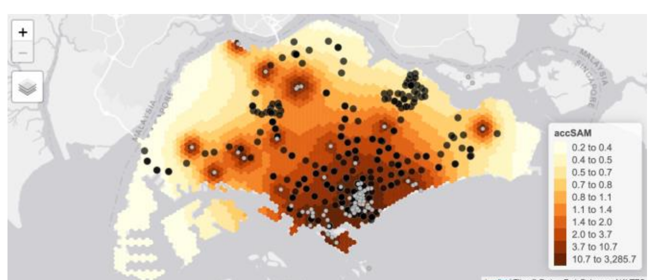

Figure 13: SAM Map with Default Settings

From Figure 13, the user can derive that SAM produces the highest accessibility values. However, the hexagonal heat map shows a smaller radius around the places of interest being considered as highly accessible, as compared to the other models.

5.4.2 Zooming in to a Specific Region. If the user wants to focus on accessibility at a particular region of Singapore, one is able to select a region from the drop-down list on the left-hand panel.

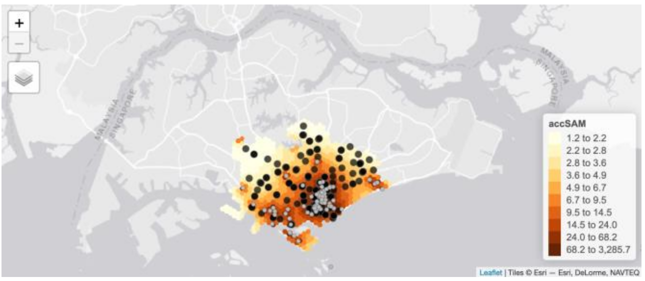

Figure 14: Filtering to a Specific Region

The graph generated will only highlight the selected region, in this case, the Central region of Singapore (Figure 14).

6 DISCUSSION

The audience who does not have programming or geospatial background are now able to easily conduct an analysis of the accessibility of MRT stations themselves. They will be able to understand that there are different models to calculate accessibility and that each model yields slightly different results. Additionally, they will understand that while some MRT stations are accessible to one place of interest, it might not be accessible to other places of interests. Policy makers can identify MRT stations with low accessibility and revisit the planning of these stations.

Overall, our results are exploratory, informing us that MRT stations are found close to places of interest, making them relatively accessible. Additionally, results from the statistical box plot make the results easier to interpret as it shows clearly which region has more accessible MRT stations compared to the rest. This thus allows users to be more confident in their statistical conclusions.

7 FUTURE WORKS

7.1 Feature for Data Pre-Processing

While the Transit-Ability application includes multiple places of interest that the user can select to analyse, the ability to upload their own dataset should also be included. This feature should come with a script that cleans and prepares the uploaded data accordingly, before being fed to the accessibility models.

7.2 Expansion of Accessibility Study

Other methods of measuring accessibility can be included like Network Distance calculation, as adopted by Zhu and Liu. Learning from their research, we can also expand the analysis of accessibility of MRT Stations to see if these stations are also accessible to opportunities like employment. The study can also be expanded to consider bus routes to study the effectiveness of public transport in Singapore. This would provide authorities with a better view of whether their objectives of their urban planning masterplan have been met. With technical developments and the acceleration of GIS solutions collecting geographical information, data such as socio-economic factors, travel time and the consideration of road conditions will be readily available for the analysis to be performed.

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