GI_Forum 2022, Issue 2
Page: 3 - 17
Full Paper
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DOI: 10.1553/giscience2022_02_s3

Investigation and Evaluation of a Transport Index for a Healthy Ageing Society

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Abstract

Challenges related to population ageing and urbanization have become major topics in society over the last two generations. With the emergence of the concept of sustainability, cities are required to develop age-friendly environments and improve the quality of urban life. This study aims to expand the currently loosely defined concept of the healthy ageing society and the framework provided by the World Health Organization (WHO). Access by elderly people to public transport is crucial for them to develop and maintain their functional abilities in society and in creating sustainable urban development. This research addresses the topic of spatial accessibility for elderly people, helping to quantify and analyse their needs and expectations within a Healthy Ageing context. As policy making is shaped significantly by the use of indicators, the investigation and discussion of indicators are important tools to facilitate policy developments and adjustments

Keywords:

healthy ageing, spatial accessibility, geographic information system (gis), indicator studies, policy development

1 Introduction

1.1 Research Motivation and Background

Five megatrends currently shaping global society are climate change, demographic shifts (especially population ageing), urbanization, the emergence of digital technologies, and increasing inequalities (United Nations Department of Economic and Social Affairs, 2020). Although ageing development patterns may vary from country to country, there are three general causes of population ageing: low fertility rates, limited exchanges between cities or settlements, and longer life expectancy (Christensen et al., 2009). Based on a UN report (United Nations Population Fund, 2021), the total number of people aged 65 years or over has been projected to double, from 703 million in 2019 to 1.5 billion in 2050 globally. As the share of elderly people is predicted to grow to 16%, this represents a coming era of a super-aged society. The number of older people in the Asia-Pacific region specifically will triple, reaching 1.3 billion by 2050.

The reasons for increased urbanization include industrialization, commercialization, the benefits of access to social services, natural increase, and employment opportunities (Bodo, 2019). Today, over half of the world's population live in urban areas (Ritchie & Roser, 2019), a figure which is estimated to reach 68% in 2050 (United Nations, 2018).

Along with ever-increasing urbanization come challenges related to transport and mobility. Assessing, understanding and eventually improving public transport are essential to accommodate the needs of society. Research trends in transport planning have evolved through three phases, each with different core concepts: from (a) traffic-based analysis that emphasized performance based on motor vehicle speeds and operating costs, to (b) mobility-oriented analysis focusing on the traveller's preferences, and travel speeds and costs, to (c) the contemporary accessibility-based analysis, which places emphasis on how the transport system can improve access for people to participate in daily life and meet their basic needs (Litman, 2013). Both accessibility and mobility are significant factors in assessing the performance of an urban transport system. While mobility focuses on the mode of transport and is related to the transport system's physical performance, accessibility is related to humans and aims to provide a better quality of life quality for urban populations. This investigation will focus specifically on improving accessibility for elderly people living in urban areas.

A well-organized transport system is one of the key elements of a city's physical environment, making positive contributions to urban mobility, safety, security, health behaviour, and social interactions. Other supporting urban functions and facilities for a Healthy Ageing society could not perform efficiently without a well-planned transport system. Accessibility (understood here as the ability to move around a city as one wishes) determines older people's connections to major social and economic activities in life. Inadequate transport planning can lead to isolation, inactivity and social exclusion, especially for the elderly (WHO, 2007). Accessibility is also defined as people's ability to reach the destination where their desired services and daily activities take place (Litman, 2021), including shopping and medical treatment, or leisure activities, visiting relatives and communicating with neighbours.

The construction of an accessibility index is a popular method to monitor the connectivity between the population and the urban transport system, as the latter has dynamic trackable characteristics, allowing quantitative statistics and readily available datasets and variables to be exploited, which can support future elderly accessibility studies (Christensen et al., 2009). Current accessibility indices focus mainly on two forms of urban mobility: public transport and walking.

Public transport system accessibility indices can be divided into three categories:

1. Destination-Based Indices consider the accessibility of the origin and destination points (O-D based index), including Utility-Based aspects (i.e. degree of user satisfaction). Such indices calculate accessibility based on travellers' preferences for activities (rather than using preset origins and destinations), as in Two-Point Distance Accessibility or Cumulative-Opportunity Measures (Litman, 2021). However, the drawback of such indices is that they require travellers' transport patterns to be collected a priori, which demands considerable time and effort. The Land-Use and Public Transport Accessibility Index (LUPTAI) allows multiple factors to be considered, including information on land use, the condition of roads and footpaths,

and public transport networks, in order to construct all parts of a journey from a preset origin to a destination. Its limitation is the availability and accessibility of data.

2. Geospatial-Based Indices focus more on features such as the Public Transport Accessibility Level (PTAL), including access to mobility services and public transport stops. PTAL considers accessibility for all points of interests (POIs) based on transport service frequency and walking distance to public transport stops. The results are classified into six categories. Improvements need to be made to PTAL regarding assumptions about population distribution. Distribution is frequently considered to be even within a census area, which is not true in most real-world situations.

3. Population-Based Indices emphasize a population's structural change over time. Such indices include the Service Accessibility Transport Disadvantage Index (SATDI) and People Near Rapid Transit index. SATDI is aimed at quantifying service accessibility and public transport disadvantage for the elderly living in non-metropolitan areas. Its limitation is that it requires information from other supporting datasets that might be difficult to acquire. The People Near Rapid Transit index is designed to calculate the number of residents living within a walking distance of 1 km to high-quality rapid transit in a city.

Walking accessibility indices can be divided into two categories:

1. Destination-Based Indices consider the accessibility of the origin and destination points (O-D based index), and include gravity-based measures – i.e. they evaluate two types of accessibility, active and passive. Active accessibility refers to the ease with which people can access personal activities such as shopping, getting to work or leisure pursuits; passive accessibility refers to the places where such activities occur and how easy it is for potential users to reach them (Cascetta et al., 2013). Gravity models take regional supply and demand into consideration along with travel impedance between zones (Bouchard et al., 1965). The limitation of destination-based indices is that they use a rather simple dataset that requires support from other complementary datasets.

2. Geospatial-Based Indices focus on geographical features such as topological aspects. Infrastructure-based and composite indices provide elaborations on the transport system using travel times, congestion and operating speed on the road network. The primary drawback of geospatial-based indices is that they do not take land-use impacts into consideration. The Walkability Index (WAI) does, however, evaluate land-use characteristics, including connectivity, heterogeneity of land use, shopping areas, and household density. Its limitation is that its simple form requires support from other transportation datasets. The Walk-score accessibility index evaluates real-world accessibility to the pedestrian infrastructure; weighting is based on a distance-decay approach, and the results are allocated to 9 categories. Its limitation is data availability. The National Walkability Index measures accessibility for pedestrians using criteria that include street intersection density, proximity to public transport stops, and diversity of land use. For all these indices, data availability and accessibility are the main limitations.

1.2 Objectives

The WHO has designed two main age-friendly frameworks: 'Active Ageing' (WHO, 2002), introduced in 2002, and 'The United Nations Decade of Healthy Ageing (2021–2030)', which gradually replaced the earlier initiative. 'Healthy Ageing' emphasizes the need for action across multiple sectors, and highlights the interactions between individuals' intrinsic capacities and the context in which they live. A well-organized social environment allows elderly people to develop or retain their ability to meet their own everyday needs, maintain their social connections, and contribute to society independently (WHO, 2020). Ensuring a convenient and comprehensive transport network is an urgent necessity to meet such goals (Awuviry-Newton et al., 2022).

Measuring and monitoring urban development towards a Healthy Ageing society requires quantification of information using a suitable transport index. However, an index that combines healthy ageing and urban transport accessibility is currently lacking. There is therefore a research opportunity to create a 'Healthy Ageing Index' (HAI) to build and improve on the 'Active Ageing Index' (AAI). Official manuals and standards as well as academic articles related to creating an HAI are mainly qualitative research and do not provide much quantitative data suitable for monitoring.

This paper investigates potential Healthy Ageing transportation indicators by making use of geospatial tools. At a later stage, our research will provide indicators and practical recommendations for policy makers, practitioners, and researchers in the fields of urban planning and design, to assist in the decision-making process. This contribution (1) looks into the quantification of Healthy Ageing as an evaluation and monitoring tool in the creation of an HAI; (2) considers the travel behaviour of older people and the barriers to travel that they face; (3) summarizes studies that analyse accessibility by the elderly; (4) summarizes spatial datasets and open-source data related to accessibility by the elderly; (5) summarizes geospatial analysis methods that could potentially be applied for the future analysis of elderly accessibility. The goal is to construct a transport index as a first step to helping visualize accessibility by elderly people, and to outline the conceptual basis for using GIS geospatial analyses. GIS tools provide the flexibility needed to perform data analysis. They also help to communicate outcomes to the public or stakeholders through visualization and representation techniques (Stylianidis et al., 2012)

In the next section, Section 2, spatial analysis methods using GIS and datasets are discussed. Section 3 presents and discusses the results of the analyses and compares them with current indicators and models for evaluating accessibility. The final section summarizes the findings and highlights future research directions.

2 Methodology

2.1 Research Data

Recent research suggests that by using three data clusters (people, places and movement) in combination with distance-based accessibility measuring methods using geospatial data a more meaningful and realistic accessibility measurement can be achieved (Levinson & King, 2020). In this paper, distance-based accessibility methods are adopted because of their simplicity and reproducibility, because datasets are globally accessible, and because the methodology should be easily implementable for comparison. The proposed datasets and data resources are listed in Table 1.

Table 1: Data resources and basic characteristics

Dataset name	Attributes	Cluster	Data resources (retrieval date)
Population (Levels: Country, District, Village)	number of people for all age groups; name of administrative area	People	Taipei City Government Department of Civil Affairs, 2021 https://ca.gov.taipei/News.aspx?n=8693DC9620A1AABF&sms=D19E9582624D83CB
Administrative area (Levels: Country, District, Village)	name of administrative area	Place	Government Open data platform, 2021 https://data.gov.tw/ https://data.gov.tw/dataset/7441 https://data.gov.tw/dataset/7442
Land-use map	type of land use; geographical area	Place	National Land Surveying and Mapping Center, 2021 https://maps.nlsc.gov.tw/ http://maps.nlsc.gov.tw/S_Maps/wmts
Transport system (bus, Youbike™, train, high-speed rail, MRT*)	station name, station ID, lines, locations	Movement	Ministry of Transport of the Republic of China, 2021 https://gist.motc.gov.tw/gist_web/MapDataService/Retrieval
Road system (Walking)	road names	Movement	OpenStreetMap, 2022 https://www.openstreetmap.org/

* MRT: Mass Rapid Transport (metro) network

The datasets used in this research comprise five main types. Population datasets contain information on people of all ages and their geographical distributions at country, district and village levels. The Administrative area datasets comprise the geographical boundaries of Taipei City for country, district and village levels. The land-use map displays the land-use types for the whole of Taipei City. The transport system datasets comprise information on the public transport stops and stations in Taipei City. Lastly, the road system data include the names of the roads in Taipei City.

2.2 Research Method

The research methods aim to integrate transport indicators into the spatial planning process and make use of cartographic visualizations using GIS. Using GIS allows the analysis of characteristics and relationships at various spatial levels, assisting people in studying, exploring and modelling geographic events by providing precise answers to questions.

The indicator which best describes accessibility for elderly people is 'access to mobility services', which has been proposed and employed by most researchers in building an initial transport accessibility index. Its definition is the 'share of population with appropriate access to mobility services'. The indicator's parameters are indicative of its broad applicability in analysing public transport systems in urban areas (World Business Council for Sustainable Development, 2015). The general equation for this index is:

$$\text{Mobility Index MI} = \frac{Xr}{Xc} \quad (1)$$

where, Xr refers to the number of people living within an accessible radius of the public transport system, and Xc refers to the total number of people living in the city. However, the accessible radius in most research focuses mainly on healthy adults and does not consider the elderly. As the number of elderly people who actually live in a specific area is unknown, their number is estimated using data from census surveys, which include the figure for the total population as well as the number of elderly people for different spatial levels (i.e., districts and villages). This value is multiplied by the area proportion of the public transport system's buffer zone, or the relevant service area (as defined in ArcGIS: https://desktop.arcgis.com/en/arcmap/latest/extensions/network-analyst/service-area.htm) intersecting with each district and village area. The resulting adapted mobility index (MIe) is:

$$\text{Mobility Index, modified for elderly population, MIe} = \sum_{i=0}^{n} \frac{X_r^E * \left(\frac{Ab}{A}\right)}{Xc} \quad (2)$$

where Xr is the number of elderly people living in the city, Xc is the city's total population, A is the total area of the city, and Ab is the buffer or service area used for assessing the number of elderly people living within an accessible radius of the public transport system. Figure 1 shows the complete workflow for implementing the Healthy Ageing Transportation Evaluation Index (or MIe), and describes in more detail the implementation steps.

In this research, both buffer analysis (which refers to straight-line distances) and network analysis (which takes real walking distances and the transport network into consideration) were carried out. The geospatial analysis results are demonstrated through thematic maps. These provide a user-friendly way to communicate the results, and might be effective in highlighting locations where public transport could be improved. ESRI's ArcGIS model builder allows for the workflow and parameters to be readily adapted, thus making the approach transferable to other settings.

Future indices based on the MIe could be implemented easily by policy makers to monitor situations and eventually to adapt strategies readily. They could be used in conjunction with conventional Transportation Accessibility Indices, although there is no single accessibility index which perfectly fits any situation; nor can any given index replace another, since each accessibility index has its own main focus (Litman, 2021). It therefore seems advisable to select those components of accessibility indices that are suitable and applicable for implementing the specific research questions at hand. The indices can then be implemented and compared simultaneously for a more comprehensive assessment of accessibility.

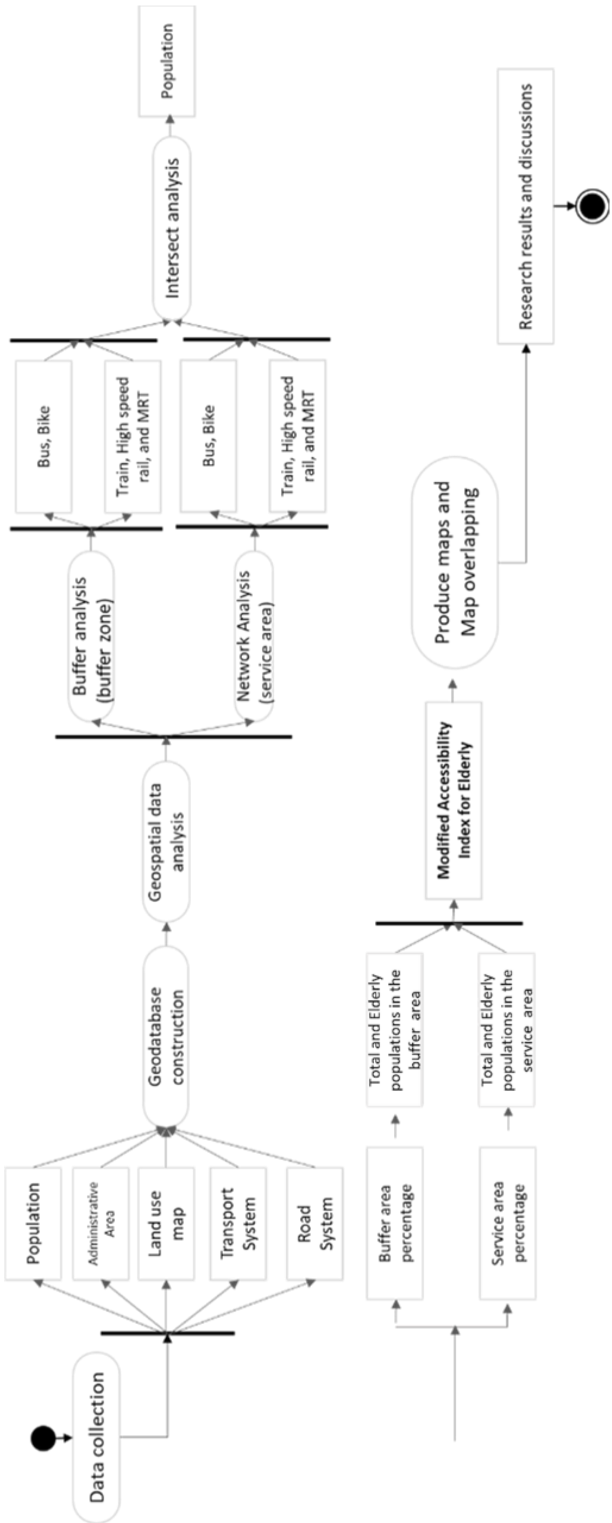


Figure 1: Workflow

Compared with the accessibility indices referred to in the literature review, the one proposed in this contribution has three main advantages. Firstly, compared to the utility-based accessibility, two-point distance, cumulative-opportunity measure and LUPTAI methods, the index does not require preset data points for the entire journey, and different public transport modes can be included together in the evaluation process, revealing all the possibilities for individuals to access public transport from their points of departure.

Secondly, compared to indices that focus solely on population and geographical aspects (notably SATDI, PNT and PTAL), the proposed index can be applied at various scales (including urban or suburban areas) specifically for the elderly populations living there, thus emphasizing both social and geographical connections rather than the overall – scattered – figures.

Thirdly, when producing the analysis area, indices such as PTAL and SATDI include buffer analysis for basic distance accessibility assessments. However, the adapted index (MIe) includes the concept of a service area, which is based on a network analysis to identify the areas that are theoretically and actually accessible by the elderly. The result is a more sophisticated analysis, which also allows comparisons to be made during the analysis process.

3 Results and Discussion

In Taiwan, elderly people carry out most of their activities close to home, and in urban regions will access locations by bike or on foot. If the distance is too great, they will switch to public transport. According to the statistics, the travel destinations are usually parks, clinics or hospitals, banks, or administrative offices. Chang et al. (2020) proposed that the travel time for elderly people should be no more than 30 minutes, and the distance should range from 0.5 km to 5 km maximum. Li & Wu (2015) further calculated that suitable walking times for elderly people should be less than 10 minutes, under various conditions. That is, under normal scenarios, a healthy elderly person is considered to have a maximum walking range of 660 to 900 metres/10 minutes. To participate in limited outdoor activities with assistance, they have, on average, to be able to walk more than 240 metres. If they want to walk around their neighbourhood, they have to walk at a speed of 480 m to 720 m/10 minutes. Lastly, if they want to cross the road safely by themselves, they have to be capable of walking at a speed equivalent to 720 m/10 minutes.

Table 1: Walking distances of 10 minutes for the elderly.

Conditions	**Walking distance (10 mins)**
Healthy	660–900 metres
Participate in limited outdoor activities with assistance	more than 240 metres
Walk around neighbourhood	480–720 metres
Cross the road safely by themselves	more than 720 metres

To assess the number of elderly people who can reach transport modes independently, by walking, the access zone was set at 720–900 metres in less than 10 minutes, under normal conditions and assuming the ability to cross the road safely on their own. The suggested research radius for buffer analysis varies according to transport mode. For public transport systems (including bus and public bike services such as Youbike™), radii of 400 metres and 500 metres are suggested for buffer and service areas respectively – i.e. limits that are closer for the elderly population.

Table 3: Buffer radius for services

Transport mode	Buffer distance	Service area distance
Bus and bike services	720 metres	720 metres
Train, high-speed rail, MRT	800 metres	1,000 metres

In order to synthesize the concepts of a sustainable urban mobility index and healthy ageing, the research radius of bus and bike services is set at 720 metres for both buffer distance and service area distance. For all trains, including high-speed rail and MRT, the distances are set to 800 metres for buffer distance and 1,000 metres for service area distance to cover walking speed and Transport system in combination with each other (Table 3).

3.1 Kernel Density Estimation

Kernel Density Estimation is employed to provide point density information for feature occurrences. Point densities (i.e. the total number of points over a search radius (bandwidth)) are represented over a continuous three-dimensional moving function, which is an effective and accurate way to interpret geospatial distribution (Krisp & Špatenková, 2010). In this method, the bandwidth determines the radius over which occurrences are searched. While estimators exist, they also have their shortcomings: much like conventional histograms, the choice of bandwidth depends partly on the visual effects desired, and hence is not truly objective. Figure 2 shows Taipei City districts with both land-use (Figure 2a) and Kernel Density analysis results based on the bus network (Figure 2b). The land-use types selected are those that relate to elderly peoples' daily lives, including commercial, residential, public facilities, as well as parks and other green open spaces. For the bus station kernel density analysis in Figure 2b, the search radius is set at 1,600 m, or double the walking distance for elderly people as discussed above, to visualize the total number of locations of bus stops/stations within the city's overall extent.

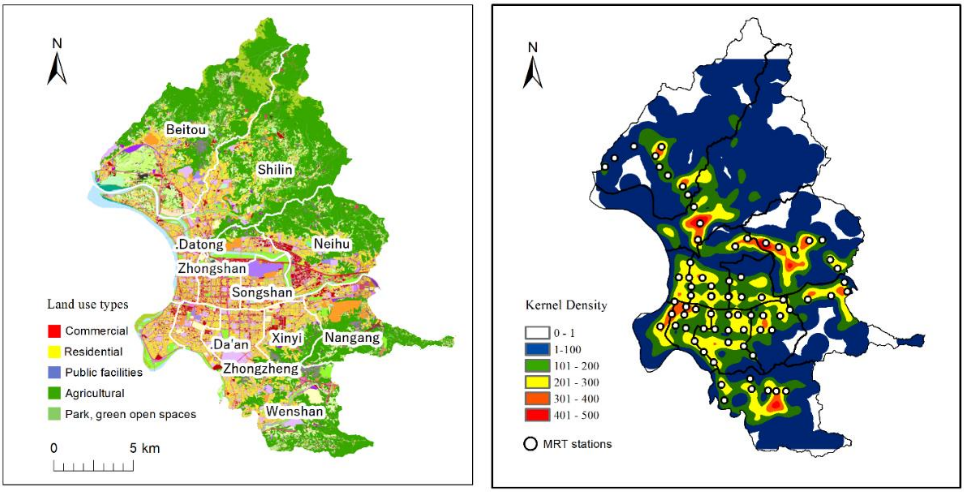


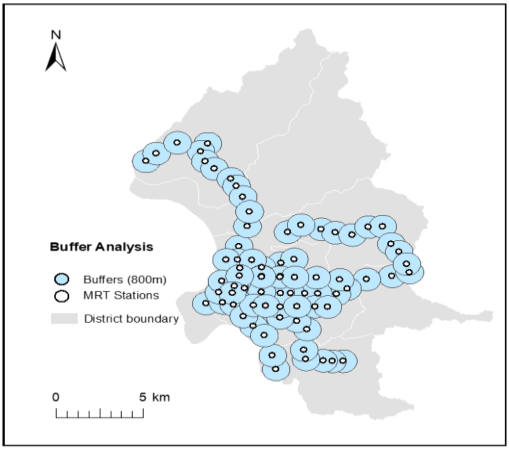
Figure 2: (a) Land-use map of Taiwan (b) Kernel Density analysis based on the local bus-stop network

A comparison of Figures 2a and 2b shows that the highest density areas (in red) coincide mostly with commercial land use, and other high-density areas mostly cover residential neighbourhoods. The lowest kernel density areas are mainly in agricultural areas, parks and other green open spaces. In a second step, the MRT station network is superimposed on the bus stop/station density map, which reveals that those areas with higher kernel density are mostly also the points where MRT stations are located, indicating that buses primarily serve as shuttles connecting people to inner-city transport systems.

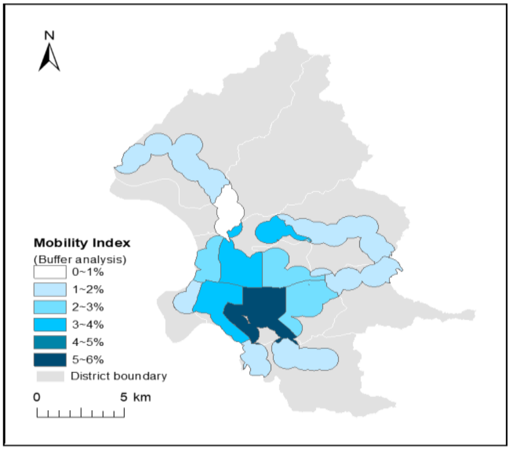
3.2 Modified Mobility Index for Elderly People (MIe)

First, the MIe is implemented using buffer analysis and service area analysis, and the results are then intersected to link buffer zones with socio-economic and geographical data (i.e., elderly populations and administrative zones). Further steps then calculate the share of the intersected buffer area to reveal the proportion of elderly people living within the accessible radius of public transport. This is then multiplied by the data on elderly population collected through census surveys in order to estimate the total number of elderly people living in the city. Lastly, the value is divided by the total number of people living in Taipei City (see equation 2).

As seen in Figure 3, a general buffer analysis method proposed and conducted in the research literature was created for the Taipei MRT network using a buffer zone of 800 m., revealing the network's total coverage. In the proposed MIe, classes are defined as fractions of the elderly population who have access to public transport locally, within a suitable walking distance. The buffer analysis results in Table 4 show that Shilin District, a district comprising large green areas in the north of Taipei, has the lowest mobility index for the elderly; Da'an District, a mixed commercial-residential area in the city centre, has the highest mobility index for older people (see also Figure 2 for reference). The results for the service area analysis shown in Table 4 confirm these findings.



(a)

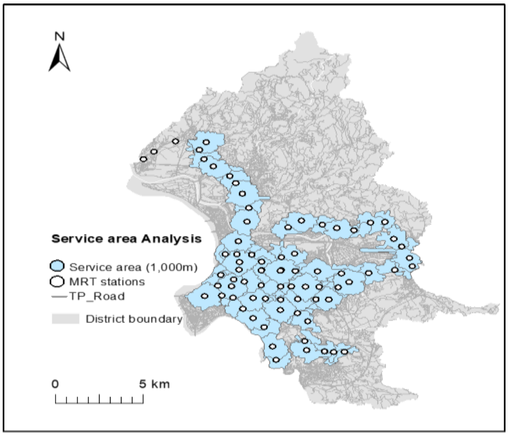


(b)

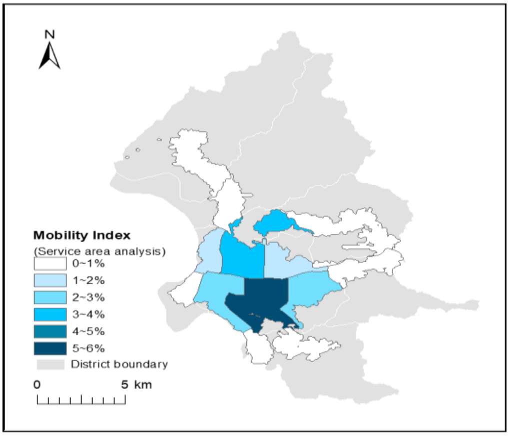
Figure 3: (a) General buffer analysis (b) the proposed MIe, based on buffer analysis of MRT stations at district level.

In the next step, a buffer analysis based on locations of MRT stations within a 1,000- metre service zone area was applied (see Figure 4). The radius chosen takes into consideration the actual road network when performing a spatial analysis. In the proposed MIe, the same classification was applied for further comparative purposes.

The trend observed is that with higher indices, the difference between buffer zone analyses and service area becomes more pronounced. While this is not surprising given the underlying formulation, it demonstrates the sensitivity of the two approaches, which leads to values that are up to 20% higher when the service area method is used.



(a)



(b)

Figure 4: (a) General service area analysis (b) the proposed MIe, based on service area analysis

A comparison of the two methods used here shows that the kernel density analysis only provides a rough overview of potential access points to the inner-city transport network for the total population. The analysis is not fine-grained enough to take into consideration the specific geospatial distribution of elderly people. Therefore, the MIe might help to improve elderly people's access to public transport by providing a clearer picture of their geographical distribution.

In the buffer and service area analysis results, at district level Shilin emerges as having the lowest and Da'an the highest values for the mobility index. It can also be seen that mobility index values become significantly larger, which indicates higher accessibility using the service area method in comparison to the buffer area.

Table 2: MRT mobility index for elderly people by buffer analysis and service area (based on district level; see district map in Figure 2).

District name	MRT mobility index (%) (by buffer area)	MRT mobility index (%) (by service area)
Shilin	0.19	0.25
Datong	1.54	1.85
Da'an	4.18	5.13
Zhongshan	2.66	3.00
Zhongzheng	2.45	2.88
Neihu	0.72	0.72
Wenshan	0.77	0.65
Beitou	0.53	0.42
Songshan	1.81	1.99
Xinyi	1.96	2.07
Nangang	0.29	0.33
Wanhua	0.66	0.88

4 Conclusions and Outlook

The topic of healthy ageing is of relevance for communities, cities, and even larger regional units when it comes to policy making and to addressing the needs of an ageing population in providing age-friendly environments and opportunities (WHO, 2020). The accessibility indicator proposed in this contribution could be a first building block for future analyses to assess whether the public transport system provides sufficient connectivity and accessibility for elderly populations in urban regions.

A potential approach was implemented by pre-processing and managing spatial and non-spatial data, and by making use of standard geospatial analyses. Kernel Density estimation methods were implemented to provide a general overview of elderly people's ease of access from inter-city to inner-city public transport systems. In the MIe, buffer analysis and a service area network analysis were conducted to better quantify and visualize accessibility by elderly people to the MRT, in the metropolitan area of Taipei City, focusing on the MRT network nodes that are within a 10-minute walk of where they live. When compared to the buffer analysis, the more detailed network analysis shows similar ordering but a clear trend towards higher index values. By continuously monitoring developments and visualizing progress through thematic maps, urban policy-makers could use the indicators to flexibly construct different time-based spatial planning strategies for villages, cities and beyond for which a service-area approach might be beneficial.

For future geospatial analyses, we plan to introduce the Two-Step Floating Catchment Area Method (2SFCA), which will be integrated into the accessibility index for Healthy Ageing. 2SFCA is an advanced gravity model, originating in the shortcomings of conventional gravity models, including difficulties of data preparation and other costs incurred in the data collecting process. It preserves the merits of earlier gravity models while taking supply and demand into considerations by measuring accessibility in two steps (Kanuganti et al., 2016). Current research into 2SFCA focuses mostly on measuring the direct accessibility of people living in rural areas to their regional health centres, but 2SFCA could be applied within a GIS environment in the development of more refined accessibility indices to address questions of mobility, in line with visions of improving elderly people's access to transport and services.

Acknowledgements

The author wishes to thank the four reviewers who took the time and effort to provide valuable suggestions and comments to help improve this manuscript. The author also acknowledges the National Science and Technology Council of Taiwan, who supported this research project under grant 109-2813-C-004-007-H.

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