ASSESSMENT OF ACCESSIBILITY OF PUBLIC BUS TRANSPORTATION IN DURBAN BY GIS-BASED NETWORK ANALYSIS

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ABSTRACT
Accessibility to public transportation system is a major concern in the cities of South Africa. The existing public transportation route network system offers poor accessibility from the residential areas to the public bus transportation nodes (bus stops/ranks) and vice versa in the cities of South Africa. Therefore, using the existing public bus transportation system in Durban, the objective of the study was to make a public transportation route network analysis to examine the accessibility of different areas in terms of walking distance and time to the public bus transportation network. A remote sensing-premised geographic information system method was used for the study. Findings suggested that different areas of the city are located at a distance between 0.5 km (0.31 mi) and 15 km (9.32 mi) from the public transport route networks. The inner-city areas including the central business districts that are located between 0.5 (0.31 mi) and 1.0 km (0.62 mi) are relatively more accessible in which people take a little above 8 minutes to a little above 16 minutes to reach a public transportation node. However, the areas located at a distance more than 15 km (9.32 mi) are highly inaccessible, and it takes more than 4 hours of walking to reach a node (bus stops). The study evidenced the current accessibility challenges in the public transport system in Durban, and the findings could assist in upgrading or re-configuring the route network system to make it more accessible.
Keywords: GIS, Remote Sensing, Spatial Network Analysis, and Transportation accessibility

1 INTRODUCTION
The sustainable public bus transportation system in South African cities is a challenge to the users. The demand for intracity movement and increased access to different parts of the cites are on the rise. Consequently, challenges of accessibility and availability of appropriate transport modes emerged. Most of the people in the larger cities travel by using either their private cars or privately operated public transportation systems such as shared taxis and minibuses. For example, according to [1], out of the total working-class people, 39.1% use public transportation (including a privately operated public transportation system) and 38.4% use their private cars. According to [2], 68.8% of South African households use taxi services daily, followed by commuter bus (21.1%) and commuter rail operations (9.9%), the negligible 0.2% use a combination of walking and either of the modes listed [1]. Moreover, a significant section of the people has difficulty in accessing either of these modes. For instance, individuals need to walk significant distances to get to public transports or privately operated public taxis ranks. Additionally, [3] contends that bus transport administrations do not cover certain routes leaving workers with the choice to walk significant distances or utilize another type of transport to get to their homes. Also, the urban areas are not amiable to a non-motorized transportation framework that individuals can use for their movement needs in short distances. Hence, a severe challenge of accessibility within the cities is experienced in the cities of South Africa. Structural Accessibility Layer and the Public Transport and Walking

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Accessibility Index are some of the operational methods of evaluating accessibility, but the article considers using remote sensing (RS) and geographic information system (GIS).

The public transportation system in the form of bus rapid transit (BRT) has been argued to have significant potential in South African cities, which can enhance the accessibility and contribute to the sustainability of the transportation system. Consequently, BRT systems have been made operational in a few large cities such as Johannesburg, Pretoria and Cape Town. Some of the other cities including Durban have a conventional public bus transportation system, although there are efforts to move towards BRT in the future. However, despite the potential, the public transportation system or the BRT systems in the cities of South Africa have not been largely accepted by the people [4]. One of the major reasons for the poor acceptance of the public transportation system is the poor accessibility of these buses from the residential areas. People allege that public transportation still uses the route networks that were enforced by the apartheid era [5,6], which lack inclusivity and accessibility to a larger section of the people particularly to the weaker and disadvantaged sections of the society. Very limited transformations in the route networks have been observed leaving a significant portion of the population of the cities. For example, suburbs or townships in and around the city having significant people belonging to the disadvantaged group have poor public transport connectivity. So, the route networks are argued to be inadequate, and people must walk a considerable distance from their residences and spent a significant amount of time to reach the public transportation nodes such as a bus or public taxi stops. In this context, an argument has emerged that there is a need to re-engineer, re-configure or modify the public transportation route networks to improve the accessibility and their uses.

Be that as it may, the re-arrangement of route network needs the evaluation of the accessibility of the public transportation framework from their homes to the urban cities regarding walking distance and time it will take the individuals to arrive at the transportation hubs, for example, transport and taxi stops and positions. Hence, the objective of the article was to assess the accessibility of public transportation networks concerning walking distance and time from the homes in the residential suburbs by using network analysis in terms of walking distance and time. In other words, the accessibility of the public transportation system in the cities was measured within walking distance and time taken by the people to reach a transportation node (bus or taxi stop/rank) located on the public transportation routes passing through or close to the residential suburbs. The study was conducted by using the existing public transportation route network system in the city of Durban. To measure the accessibility, a route network analysis was conducted by using GIS technique.

2 LITERATURE REVIEW

2.1 Accessibility and public transportation

Accessibility in transportation can be characterized as physical access to products, administrations and goals. It is the relative ease of arriving at an area or territory or goal [7]. At the end of the day, it is the simplicity at which individuals can accomplish any ideal facilities, items or activities by moving from one location to another location or within a location by the use of transportation means [7]. It is reliant on the spatial dissemination of potential goals comparative with the origin–destination of an individual. It is also dependent on the ability of the transportation framework in accessing spatially isolated areas and the attributes of the individual to utilize the transportation framework. Furthermore, the extent, quality and character of the activities influence accessibility. Hence, accessibility investigation in geospatial technological planning, implementation and development envelops spatial and financial perspectives, requires broad information and includes route network analysis [8,9].

The primary aim of public bus transportation is the movement of people and goods and information and the rapid movement of troops in case of emergency. Several proofs have demonstrated that public transport assists with diminishing traffic blockages, build work, brings down transportation and business costs, brings down the average cost for basic items and upgrades business development [10]. Also, it lessens harmful contamination and improves air quality [11]. Furthermore, it empowers individuals to go without having a vehicle, at a steady cost and timetable. More significantly, it makes residential areas accessible, encourages new endeavours and working zones, diminishes accidents and overall reduces the need for infrastructure [12]. However, the success of public transportation is dependent on the route network that provides accessibility to the people.

2.2 Public transportation and network analysis

Public transportation is important because it allows people to take part in human activities. There are several types of transportation systems; however, the focus of this study is on the public transportation system, which transfers individuals from one geospatial area to another in urban areas and suburbs. The expansion in populace and ensuing increment in financial exercises have mounted weight for improvement of public bus transportation in the urban areas and suburbs to enable day by day travel needs of individuals [13]. The public bus transportation system operates through a route network system in a city to provide accessibility to the people. So, the route network for public bus transportation forms an important part of the public transportation operational planning process. The organization of routes, scheduling, etc., forms an enormous part of the public transportation operation system [14]. The public transportation operational process consolidates the structure of network plans and the confirmation of related operational characteristics, for instance, timetables, booking of transports and drivers, frequencies, moving stock sorts and so forth [15]. Nevertheless, the public transportation network constitutes a system of nodes and links. The location of these nodes and the creation of the routes going through these nodes to pick and drop the passengers are crucial for the achievement and accessibilities of the public transport transportation network in a city. Notwithstanding, the straightforward idea of one area interfacing with another rapidly turns into a complex way as the number of nodes and links increases [16]. So, network analysis is essential to examine the accessibility and serviceability of the network and create optimal solutions to improve the accessibility and serviceability.

2.3 GIS approach of network analysis

Until the emergence of GIS in 1968, network analysis was resolved using project management tools. ArcGIS network analysis is a network-based spatial investigation program for taking care of complex transport issues. As indicated by [17], network analysis is a technique for taking care of system issues, for example, navigability, serviceability, the pace of flow, or limiting, utilizing system availability. GIS is an adaptable instrument to coordinate land use and transport framework segments in accessibility metric, permitting the examination of various basic improvement situations as far as their impact on accessibility without the need to run conventional information concentrated 4-step transport model [18]. It is the theoretical foundation of mathematical subdisciplines of graph theory and topology [19].

Any network system comprises of vertices and the edges that interface them. Network analysis by GIS makes a convincing exploration of a worldview because its structure can so naturally show complex frameworks and can understand the complex frameworks, for example, a transportation network. GIS can examine a system without meddling with the different spatial and cartographic properties of a system such as a shape or a length, link, nearness and occurrence, which do not fluctuate if the system is distorted by a cartographic procedure, for example, a projection. The perpetual quality of these properties permits them to fill in as a reason for depicting, estimating and examining systems [19]. Furthermore, network analysis using GIS helps to show lapses of a network. It can show details of the areas that lack roads, facilities and transport services: It can also show areas above accessibility [17] as demonstrated by this study.

ArcGIS can perform network analysis in six ways such as 1) route analysis, 2) nearest feature investigation, 3) service area analysis, 4) origin–destination (OD) cost grid examination, 5) vehicle directing issue investigation and 6) area allotment investigation layers [17]. This study used the service area analysis method. The main advantage of network analysis is that extremely complex amounts of connections can be analysed and structured well. This brought about applying GIS techniques for the study to produce an interactive map.

3 STUDY CONTEXT AND RESEARCH METHODS

3.1 Study context: public transportation network, Durban

Durban in South Africa is a fast-growing city with increased demand for efficient, secured and affordable public bus transportation. The city of Durban has an existing public transportation system that services different suburbs in the city and the townships in and around the city. However, most parts of this sprawling city are not connected and accessible by the existing public bus transportation system. It is alleged that the current public transportation system is not offering accessibility to a large segment of the people specified in the suburbs and townships at the fringe of the city. For example, people must walk significantly long distances and spent a considerable amount of time to reach the bus or taxi stops from their homes in the suburbs to access the public transportation system. The public bus transportation system of Durban is poorly distributed and has not fulfilled its purpose of accessing the urban areas or cities evenly from the nooks and cranny of the Durban city, which is causing the larger populace without their private vehicles untold hardship [20].

An evaluation of vehicular usage over the last 15 years revealed a decrease in the utilization of public transport and quick development in vehicle possession making the transportation framework in the city largely unsustainable (Table 1). However, to make the transportation system more sustainable, a move for an integrated BRT system named ‘Go Durban’ has been under consideration for implementation, in recent times. The proposed BRT system is envisaged to be an upgrade on the existing integrated transport plan; it is expected to roll out in several phases. The current phase one, which is expected to be implemented, has nine corridors denoted by C1-C9 operating daily from C1, the bridge city, to C9 in Umhlanga. It has seven transfer stations, four parks/ride and thirteen facilities [21]. However, it will take a significant time until the proposed BRT system becomes fully operational. Moreover, with the increase in the population and demand for increased transportation needs in the city,

Table 1: Vehicular usage in Durban.

Items	The year 2005	The trend year 2020	Net growth 2005-2020
Total person trips	699	853	About +22%
Trips by car	333	498	About +50%
Trips by public transport	366	355	About -3%
Modal split	52:48	42:58	n.a

Source: [22].

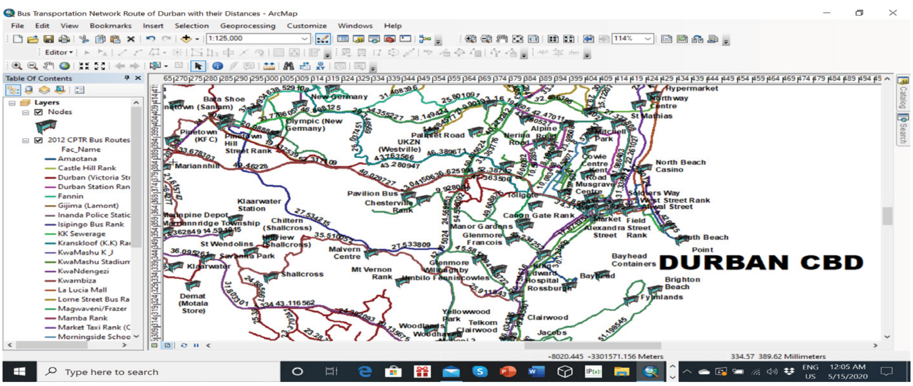

Figure 1: Showing part of Durban's public transportation network (central business district).

the challenge of accessibility might remain the same if appropriate interventions to improve accessibility are not taken. Furthermore, until the new BRT system comes into full operation, the old public transportation system is expected to serve the larger segment of the people. Therefore, there is a need for the network analysis to examine the accessibility challenges of the existing public transportation network, which might also inform the expected challenges with regards to the accessibility of the new BRT system.

3.2.1 Research method

A systematic research method for data collection and data analysis by using GIS technique was adopted. The flow chart describes (Figure 2) reveals the steps followed in the research method adopted for this study. GIS method was found suitable in this study because of the nature of data and the requirements of network analysis.

GIS is a computerized application intended for the acquisition, saving, control, evaluation and presentation of geographic information. Spatial location is the component that recognizes geographic information from every other form of information. Spatial location is the premise of the investigation on account of the capacity of GIS products (maps/plans), measurements, which tie various types of data together concerning a geographical area [23]. Besides, the data model remains the core of any GIS strategy. A data model is a theoretical form of some real-world circumstances used to sort out data in a database. Likewise, this database ought to furthermore be divided into datasets. The datasets are subisolated into the segment classes, which include two classes, for example, points and lines. Data models generally comprise

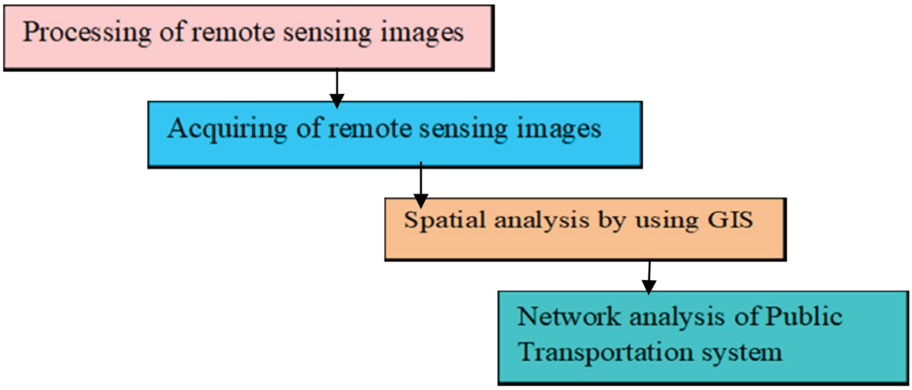

Figure 2: Methodology chart.

of three significant segments. The first is a lot of information articles or element types that form the fundamental structure that obstructs the database. The subsequent segment is a general rule, which obliges the events of substances to those which can lawfully show up in the database. The last segment incorporates administrators that can be applied to elements in the database [8]. Furthermore, the utilization of RS upgrades the proficiency of GIS. RS is the study of capturing, preparing and revealing images and related information that are acquired from ground-based, air-or space-borne instruments (charged couple devices) that record the relationship between the features (target) and electromagnetic radiation. In this manner, through RS data features that are situated on the surface of the earth can be captured. Since GIS linked to RS data is a valuable tool to analyse spatial data of the earth's surface efficiently and accurately that can be used in decision making, it was deemed relevant for network analysis of public transportation route network and thus used in this study. The details of data collection and analysis are discussed in the following subsections.

3.2.2 Data Collection

Data relating to the current operational public transportation network were collected from the Department of Transport (DoT) in the eThekwini Transport Authority (ETA). The spatial datum collected was a shapefile that includes the current imagery of the study area (ortho-rectified image), which served as a base map. The RS data acquired were then processed to make them compatible with spatial and network analysis by GIS techniques by using ArcGIS software. The primary data of the study were spatial data of the current public transport records (CPTR) of Durban.

3.2.3 Data analysis

As mentioned previously, GIS techniques by using ArcGIS software were applied for analysing the RS data obtained. Network testing utilizes resistance (impedance) evaluation in distinguishing a route type. So, first, georeferencing was performed by using global positioning system gadget (handheld) to pick a few control points at notable landmarks, and their coordinates were acquired utilizing ground-truthing. These coordinates were used to perform the georeferencing, which provided credibility to the data acquired and was saved in the computer as shapefile. The data were uploaded to the ArcGIS software for several tasks to be performed. However, spatial and non-spatial data were grouped, to perform network analysis. The performing of network analysis involves the following steps:

- Network analysis device in ArcMap (GIS Software) was opened and operated.
- Network analysis layer and parameters were inputted into the device.
- For verification ground-truthing was performed and checked with the network investigation layer data.
- Features without spatial attributes were evaluated and fixed to the spatial data.
- The procedure to recognize a perfect system from the other was focused to confine the acceleration path and travel time.
- The impedance measurement was done; network evaluation was performed on the routes. There are different sorts of impedance's, yet the shortest time point is progressively critical.
- ArcGIS was utilized for map embellishment.

The context and setting of this study were to show how network analysis can be performed to evaluate the degree of accessibility of a spatial location relative to the others in Durban. It was also identified locations that need road networks to enhance public bus transportation network. In other words, it was needful to identify the areas with less accessibility and to find the best approach to improve accessibility.

In this context, [3,24] suggested that the total length of the pedestrian links to the bus stop should be a circle within a radius of 400 m (0.25 mi) from the settlement. It helped to evaluate the accessibility concerning walking speed, i.e., distance over time from different settlements serviced by a bus stop. Therefore, the average walking speed from the settlement to the bus stop was measured to be distance 400 m (0.25 mi) and time (10 minutes, 26 seconds), resulting in walking speed of approximately 2.3 km/h (1.43 mi/h). This simply implies that to walk for 400 m (0.25 mi), it will take 10 minutes, 26 seconds at a walking speed of 2.3 km/h (1.43 mi/h) as shown in Figure 3.

According to the standard of 400 m (0.25 mi) circumference buffer suggested by the literature to the centroid (bus stops), distances from different areas from the residential settlement where the passengers lived were calculated to determine the average walking speed as denoted in Table 2.

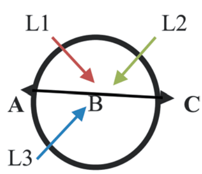

Figure 3: Demonstrates circular buffer of 400 m (0.25 mi) showing walking distances to the bus stop (not to scale).

L1 → Walking distance from settlement 1 to bus stop B
L2 → Walking distance from settlement 2 to bus stop B
L3 → Walking distance from settlement 3 to bus stop B
A-C ↔ Existing Bus route
B ○ Centroid point (bus stop) 400 m (0.25 mi) circumference as obtained from the literature.

Table 2: Outcome of walking distances from the 3 locations (speed is constant as calculated).

S/No	Distance (km)	Time (h)	Speed (km/h)
L1	0.365	0.159	2.3
L2	0.332	0.144	2.3
L3	0.394	0.171	2.3

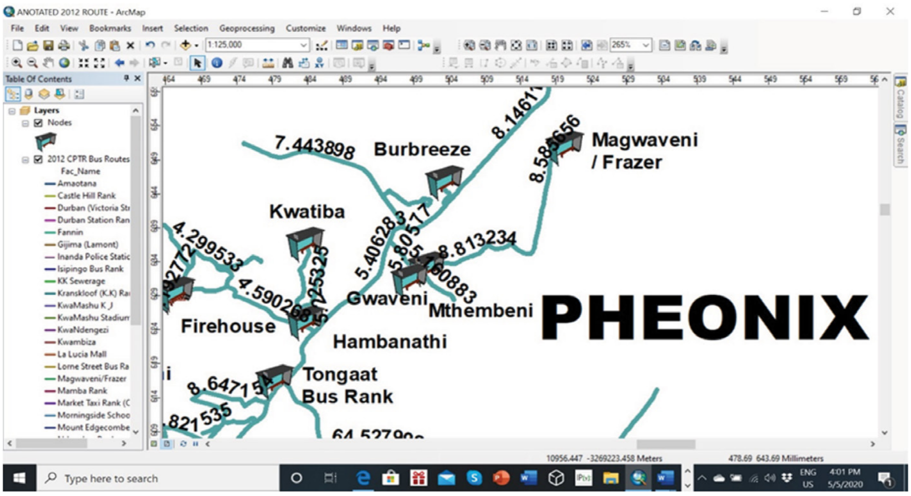

Figure 4: Details of routes, bus stops and distance of each route in km around Phoenix.

Physical access to a travel stop is deciphered as far as the vicinity of the traveller's OD to the closest bus stop [7], which is by and large accomplished by walking, riding a bike or driving a vehicle for a short distance [25]. So, accessing a bus stop generally in the study area or so to say in South Africa is achieved mainly by walking. Therefore, in this study, a reference average walking speed of about 1.3 m/s (4 ft/s), and 5 minutes of walking, which is about 400 m (1312 ft) in terms of walking distance was taken [26]. Based on this assumption, the optimal walking distance and time from the residences in the suburbs to the nearest bus stops were calculated. For example, a public transportation route passing through Phoenix of Durban (Figure 4) was taken to demonstrate the calculation. The basis of calculation of distance and time are shown in Figure 5. To calculate some centroids were identified in the suburbs, which should act as proxies of residences from where the distance and walking time to bus stops were calculated. Distances and walking times on different routes from these centroids to bus stops on the public transportation route network were calculated (Figure 5), and the example of the results of such calculation and implication are presented in Table 3. The table shows different routes from origin node A^1 and destination node A_1 and the distances as well as walking times. A lower distance and lesser walking time represent higher accessibility, which can be ascertained from this table, for example, the route shown by W1 is the most optimal route thus more accessible.

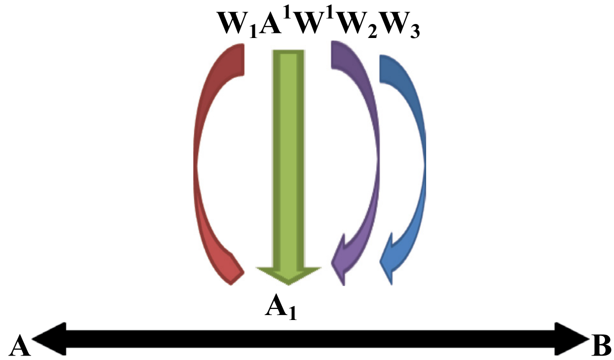

Figure 5: Shows how the optimal walking distance (W^1) was determined.

A-B is the public bus transportation route attached to the settlement residential area one.
A^1 is the residential area one.
A_1 is the centroid/bus stop along the route A-B.
W_1 is walking distance from residential area one to the centroid A_1.
W_2 is walking distance from residential area one to the centroid A_1.
W_3 is walking distance from residential area one to the centroid A_1.
W^1 is the proposed optimal walking distance from residential area one to the centroid A1.

Table 3: Example of calculated walking distance from the origin to destination.

Origin node	Destination node	Distance (km)	Walking Time (h)	Accessibility
A^1	A_1 along A-B	$W_1 = 0.360$	00:09:23	Good
A^1	A_1 along A-B	$W_2 = 0.393$	00:10:15	Good
A^1	A_1 along A-B	$W_3 = 0.408$	00:10:39	Not Good
A^1	A_1 along A-B	$W^1 = 0.387$	00:10:06	Good

Walking Distances < (0.4 km) is considered good access and > (0.4 km) not good access.

4 RESULTS AND DISCUSSION

Walking distance and time were used to resolve the problems associated with the accessibility of public bus transportation of Durban. It was achieved by performing network analysis (of the service area) of the Durban public bus transportation route network. Service areas were created to evaluate accessibility. Concentric service areas revealed how accessibility changes with resistance (impedance). With the situation, it was possible to use it in identifying how much land area was available and how much of any features within a neighbourhood or the region [9,27].

Figure 6 represents the accessibility network analysis of the existing public transport network. It shows in detail the various areas (demarcated in polygons) and their access to the bus stops or public transport facilities. It was found that most of the areas (shown in polygons) are located at a distance between 0.5 km (0.31 mi) and 15.0 km (9.32 mi) (Table 4). Figure 7

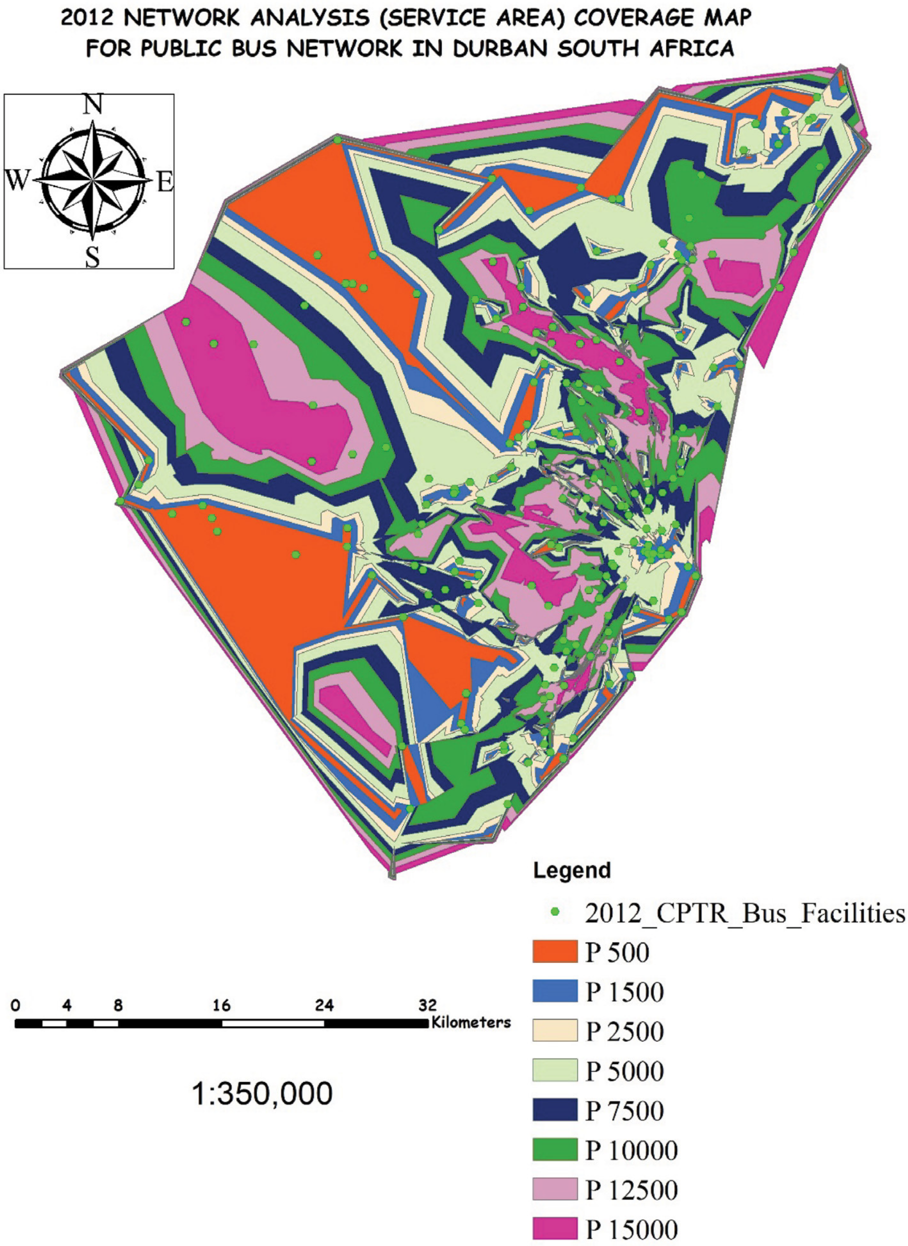

Figure 6: The network analysis of public bus transportation of Durban.

presents the areas that are located within 500 m (0.31 mi) from the public transport nodes. People walk for 8 minutes and 6 seconds to reach the bus stops in the areas that are located within 0.5 km (0.31 mi). Similarly, it takes a walking time of 16 minutes and 13 seconds to reach the bus stop that is located at 1 km (0.62 mi) distance. The network analysis of the various suburbs shows that the average bus stop walking time from the central business district

Table 4: Parameters used to perform the network analysis.

S/No	Object ID	Distance (m)	Area (square km)
1	12565	15000	219
2	12566	12500	260
3	12567	10000	331
4	12568	7500	382
5	12569	5000	434
6	12570	2500	176
7	12571	1500	175
8	12572	500	320

The details in Table 4, shows the areas of polygons in square kilometre and the distances in meters used in performing the analysis. The object identification elaborates on the different spatial locations considered for the network analysis.

(CBD) to the nearest bus stop is 8 minutes and 6 seconds. However, people in the areas that are located at a distance of 15 km (9.32 mi) will walk for 4 hours, 3 minutes and 9 seconds to reach the nearest bus stop; therefore, they are highly inaccessible (Figure 8). Thus, it is found that the inner-city areas including the CBD are relatively more accessible to the public transportation system whereas the areas that are outside the city centre or inner-city area are highly inaccessible to the public transportation system. The results attained agrees with the relatively similar methods used by Ajay and Bharti (2013) and Kevin (2007) [8,19] in their previous work. Furthermore, this finding corroborates the findings of Pau (2019) [28], thus justifying the approach used in the study. Furthermore, the context of Africa, this analysis also complements the findings of Dondo and Rivett (2004) that it can assist in calculating the optimal path between any two points such as an activity centre and public transport node (bus stop) and also assignment of public transport vehicles to the most efficient route [29].

5 CONCLUSIONS

The demand for intracity movement and increased access to different parts of the cites are increasing in South Africa. Consequently, challenges of availability of public bus transport modes and accessibility have emerged. Therefore, using the context of the Durban city of South Africa, the study investigated the challenges of accessibility of the existing public bus transportation system as regards (speed) walking distance and time from the place of residences to public bus nodes on the public transportation network and vice versa. The GIS techniques were employed in performing the network analysis. The network analysis was conducted by using the RS-derived data (shapefiles) obtained from the DoT, ETA, Durban KwaZulu-Natal. Service area network analysis was performed and presented as an embellished map with resolution of 300 (dpi). The network analysis revealed that different suburbs and activity areas of the city are located at a distance between 0.5 km (0.31 mi) and 15 km (9.32 mi) from the public transport route networks. The areas located in the inner-city area and CBD have relatively higher accessibility to public road transportation. People take between 8 and 16 minutes on the average to walk a distance between 0.5 km and 1.0.km to reach a public transportation node such as a bus stop/rank. However, the distant areas that are more than 15 km (9.32 mi) are highly inaccessible. It takes more than 4 hours to reach a node

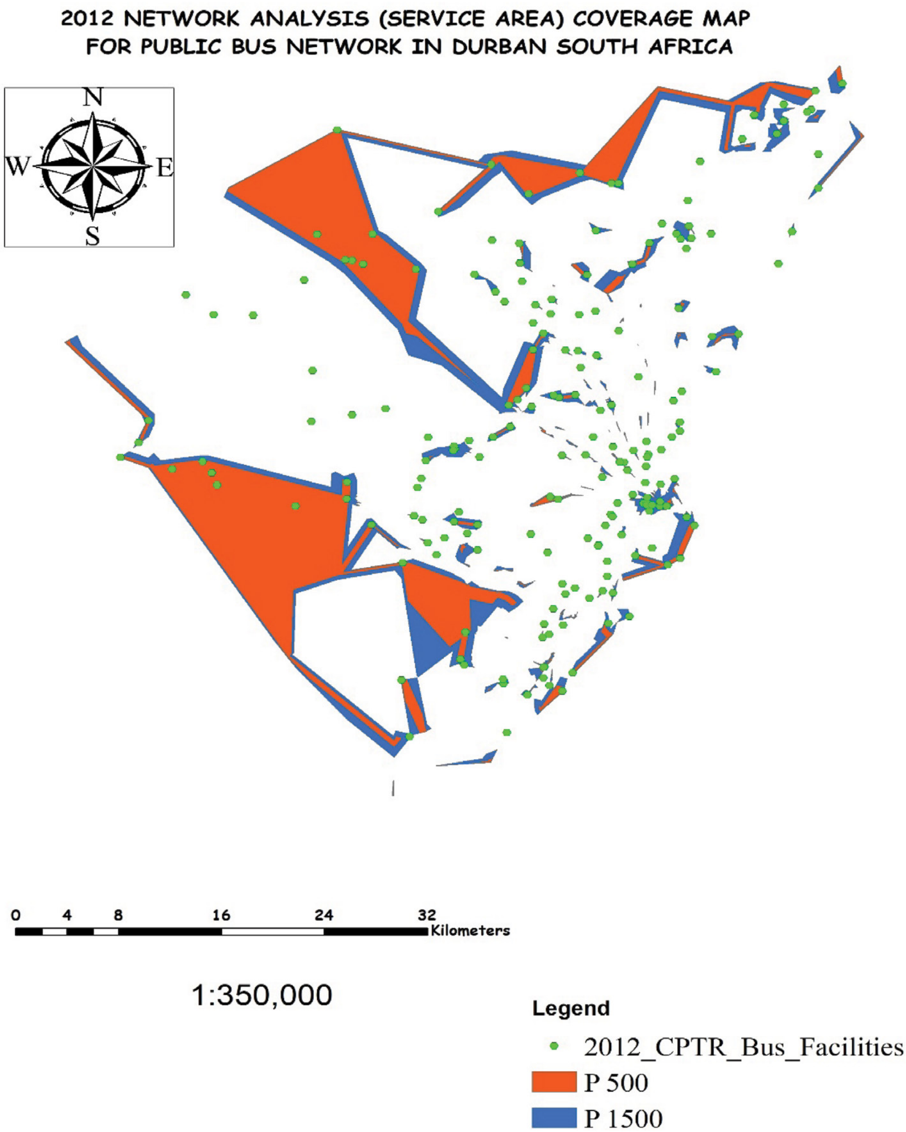

Figure 7: Network analysis of public bus transportation of Durban showing areas with high accessibility.

(bus stops on the current Durban public bus transportation system) by walk in these areas. It indicates that the suburbs at the periphery and townships around the city do not have adequate access to the public bus transportation system.

The study contributes to understanding the variability of the accessibility challenges that are faced by the people in different spatial locations of South Africa. The findings have practical relevance as it can assist in reconfiguring and upgrading the public transportation route network to enhance accessibility for the people specifically located in the outer region of the cities of South Africa. The findings have practical relevance as it can assist in reconfiguring

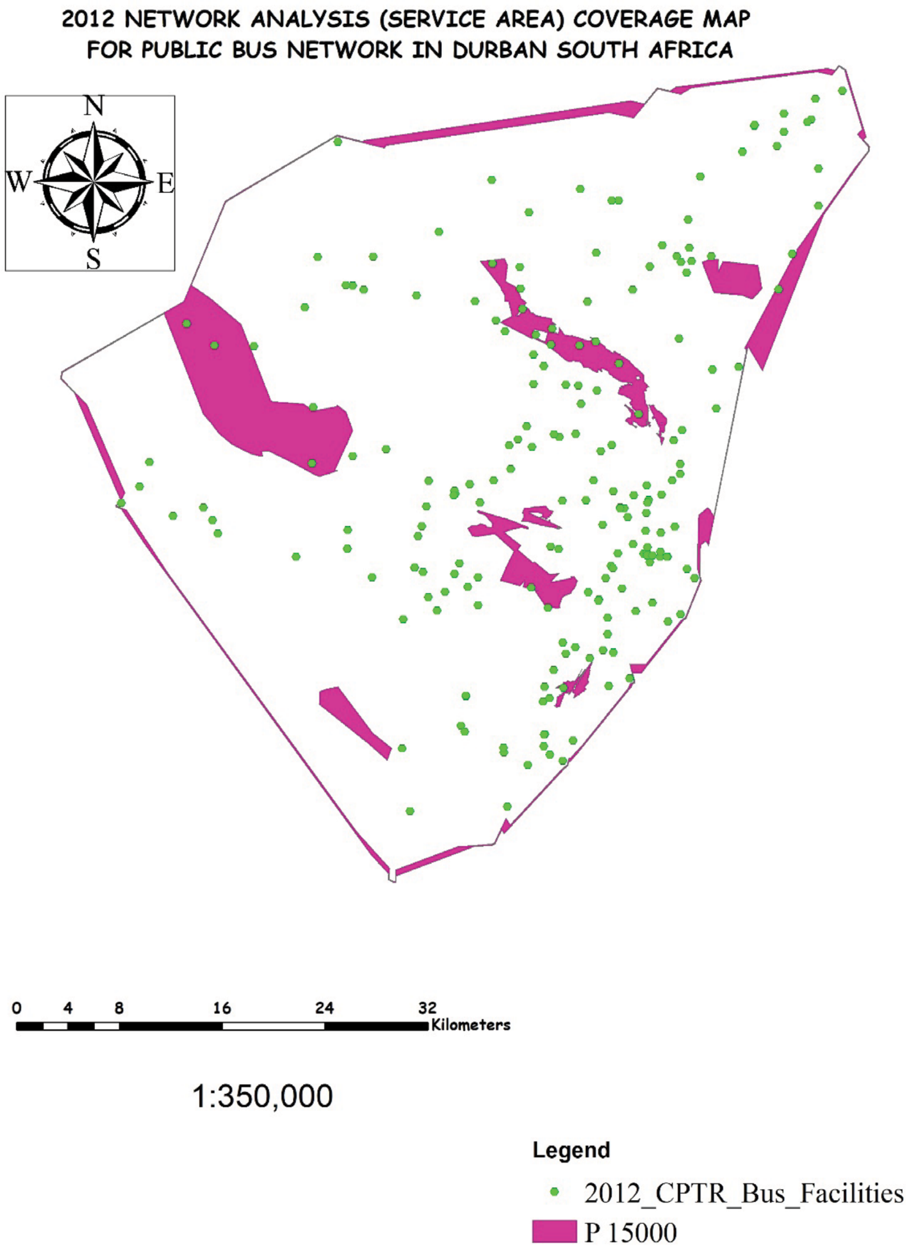

Figure 8: Network analysis of public bus transportation of Durban showing areas with low accessibility.

and upgrading the public transportation route network to enhance accessibility for the people specifically located in the outer region of the cities of Durban South Africa. Moreover, the public transport operators can also identify more efficient routes and re-assign their vehicles to these routes. Also, the study can assist in developing policies and strategies for location of bus stops in order to provide higher accessibility to the people as well as creating alternate and efficient public transportation routes. Furthermore, the study used a GIS-based spatial approach to analyse the public transportation route network, thus offering an alternative method for assessing public transportation accessibility challenges. Perhaps, similar studies may have to be in existence in some parts in Africa and developed world, but not in Durban, South Africa, the study area of this research. The result of similar studies at the world perspective also agrees with the study.

The study had certain limitations that include the non-availability of detailed updated transportation route network maps and relevant data. Furthermore, the extent of the evaluation was restricted to measuring accessibility with regard to walking distance and time, and the topography, terrain condition, concentration of activity areas and density of population were not considered, the incorporation of which is the future scope of the study.

The study, however, indicated that while inner-city areas are accessible, the outer-city areas have severe public transportation accessibility challenges, and there is a need for reconfiguration and upgrading of the current public transportation route network to enhance accessibility in those areas of the Durban city. The results of the research will enhance the planning of the city by the stakeholders in the transport industry and will be made available to the transport authorities at request for the need to draw a framework.

REFERENCES

[1] Statistics South Africa, http://www.statssa.gov.za/?page_id=739&id=3 accessed on 05, June 2020.

[2] National Household Travel Survey, Statistics South Africa, 2014, 6.

[3] Mtizi, C., Southern African solutions to public transport challenges. 36th Southern African Transport Conference (SATC 2017) ISBN Number: 978-1-920017-73-6, 2008.

[4] Ferranti, E, Andres L, Denoon-Stevens, S.P., Melgaço, L, Oberling, D, & Quinn, A. Operational Challenges and Mega Sporting Events Legacy: The Case of BRT Systems in the Global South. Sustainability 2020, 12, 1609; DOI:10.3390/su12041609, 2020.

[5] Aropet R., Southern African solutions to public transport challenges. 36th Southern African Transport Conference (SATC 2017) ISBN Number: 978-1-920017-73-6, 2017.

[6] Findley, L & Ogbu, L., South Africa: From Township to Town. Places Journal Publication, 2011.

[7] TCRP Report 19, Guidelines for the Location and Design of Bus Stops. Transportation Research Board Executive Committee, 1996.

[8] Nagne, A.D & Gawali, B.W., Transportation Network Analysis by Using Remote Sensing and GIS A Review. International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.comVol. 3, Issue 3, May-Jun, pp.070-076, 2013.

[9] Liu, S. & Zhu, X., Accessibility Analyst: An Integrated GIS Tool for Accessibility Analysis in Urban Transportation Planning. Environment and Planning B: Planning and Design, 31, 105-124, 2016.

[10] Berg, C.N, Deichmann, U, Liu, Y & Selod, H., Transport Policies and Development, The Journal of Development Studies, 53:4, 465-480, DOI: 10.1080/00220388.2016.1199857, 2017.

[11] Manisalidis, I, Stavropoulou, E, Stavropoulou, A, & Bezirtzoglou, E., Environmental and Health Impacts of Air Pollution: A Review. Public Health, https://doi.org/10.3389/fpubh.2020.00014, 2020.

[12] Norbäck, R., The Role of Public Transport and It's Financing. Nobina Group, 2017.
[13] Reza, Z.F, Elnaz, M, Szeto, W.Y. & Hannaneh, R., Review of Urban Transportation Network Design Problems. European Journal of Operational Research, 2013, v. 229 n. 2, p. 281-302, 2013.
[14] Department of Transport, Public Transport Strategy South Africa, 2007.
[15] Lu, K., Han, B. & Zhou, X., Smart Urban Transit Systems: From Integrated Framework to Interdisciplinary Perspective. Urban Rail Transit4,49–67 https://doi.org/10.1007/s40864-018-0080-x, 2018.
[16] Caschili, S., COMPLEXNETGIS: A Tool for The Analysis of Complex Spatial Networks. Research Gate publication, 2010.
[17] Esri Support GIS Dictionary. https://support.esri.com/en/other-resources/gis-dictionary/term/79246537-2e54-45f4-a5b9-64a1bfc225b2, Accessed on 17 June 2020.
[18] Zuidgeest, M.H.P, Brussel, M.J.G, & Maarseveen, M.F.A.M.V., GIS for Sustainable Urban Transport. ISPRS International Journal of Geo-Information. University of Cape Town, South Africa, 2015.
[19] Curtin, K.M., Network Analysis in Geographic Information Science: Review, Assessment, and Projections. Cartography and Geographic Information Science 34:2, 103-111, DOI: 10.1559/152304007781002163, 2007.
[20] Ngubane, L., The State of Public Transport in South Africa. Public Transport and Safety Symposium, 2018.
[21] Go! Durban, City of eThekwini. State of Cities Report Dashboard Indicators, 2016.
[22] Public Transport Plan, eThekwini Transport Authority, 2005.
[23] Graham, S.R., Carlton, C, Gaede, D, & Jamison, B., The Benefits of Using Geographic Information Systems as a Community Assessment Tool. Public Health Rep, 2011.
[24] Foda, M.A. & Osman, A.O., Using GIS for Measuring Transit Stop Accessibility Considering Actual Pedestrian Road Network. Journal of Public Transportation, Vol. 13, No. 4, 2010.
[25] Murray, A.T, Wu, X., Accessibility trade-offs in public transit planning. J Geograph Syst 5, 93–107 https://doi.org/10.1007/s101090300105, 2003.
[26] Ammons, D.N, Coe, C. & Lombardo, M., Performance-Comparison Projects in Local Government: Participants' Perspectives. Public Administration Review • January/February, Vol. 61, No., 2001.
[27] Soares, C.A.M & Quintanilha, J.A., Identification of Trip Generators Using Remote Sensing and Geographic Information System. Transportation Research Interdisciplinary Perspectives Volume 3, December 2019.
[28] Soto, P.D., Chapter 13 Network Analysis to Model and Analyse Roman Transport and Mobility of Finding the Limits of the Limes Modelling Demography, Economy and Transport on the Edge of the Roman Empire, 2019.
[29] Dondo, C. & Rivett, U., Spatial information systems in managing public transport information, South Africa journal of Information Management, Vol.6, No. 2, pp. 1-14, 2004.