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The case of Dar es Salaam, Tanzania

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February, 2019

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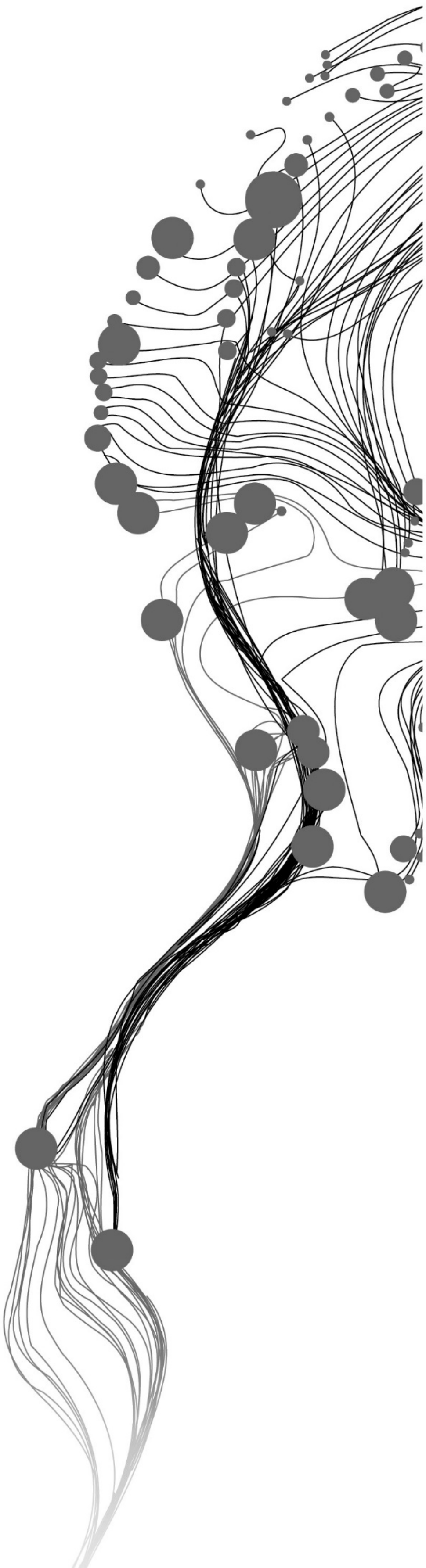

Transit Accessibility and Equity Evaluation of Bus Rapid Transit System: The case of Dar es Salaam, Tanzania

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Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
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ABSTRACT

In recent decades, one of the popular sustainable mass transport systems implement in the Global South including African cities is Bus Rapid Transit (BRT) system. BRT system has been embraced not only because of its unique characteristics of promoting sustainable mobility, but it can achieve progressive benefits such as enhancement of access for all socio-economic groups, particularly the poor who are car-less. It is in line with this, this present study aimed to evaluate the equity based on accessibility to job locations across socio-economic groups who are within 20 minutes walking distance to the proposed Dar es Salaam Rapid Transit (DART) system, and explore the possible residential areas for the DART system extension in order to enhance equity within Dar es Salaam. To do so, this study used both spatial and non-spatial datasets, with the quantitative methodological approach (i.e., spatial and statistical methods) to explore the likely future impacts of the DART system focusing on vertical equity. A GIS-based network analysis was used to estimate the physical accessibility while Lorenz and Gini-indices to measure inequity levels across socio-economic groups. In short, it was found that within the city the proposed DART system can serve a large residential area with a large number of population and provide more access to the bus stops within a desirable walking distance of 20 minutes to the least deprived population compared to other deprived population. Secondly, the proposed DART system can promote high potential of opportunities for interaction as it can connect a large number of population to countless formal job locations but does not result in the equitable spatial distribution of job accessibility across the socio-economic groups as measured by the Gini-indices. Thirdly, the current service area by the proposed DART system signifies its extension of the corridors to the city's periphery where the most deprived population reside. This can enhance fairly equitable access not only to the bus stops but also to the job opportunities. The DART system 's extension can be accompanied by the implementation of land use policies on effective spatial distribution of both formal and informal activities to reduce the city's monocentric structure in terms of employment.

***Keywords*:** Bus Rapid Transit (BRT), Accessibility, Equity, Socio-economic groups, GIS network analysis

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GIS - Geographic information system
TNBS - Tanzania National Bureau of Statistics
DART - Dar es Salaam Rapid Transit
DSM - Dar es Salaam
MPI – Multidimensional Poverty Index

1. INTRODUCTION

1.1. Research background

In recent decades, the urban population around the world has dramatically increased. This has resulted in challenges such as urban sprawl, slum creation, lack of affordable housing, rapid motorization etc. (Cohen, 2006). It is estimated that by 2050 around 66% of the world's population will live in urban areas (UNDESA, 2014) and this will lead to high demand for physical infrastructure such as transport infrastructures.

Transport in an urban context is a lifeblood of cities and has two modes of services which include public and private transportation (Verbich & El-Geneidy, 2017). In this 21st century, public transport calls for global attention to ensure mass mobility and meet the demands of all people. Also public transport, especially in developing countries, has become the most viable service over non-motorized transport as it enhances accessibility to services that are beyond walking and cycling distances (Wright, 2002). It helps to boost the economy and wealth of the whole city. Moreover good public transport reduces over-dependence on private vehicles because it is affordable although not for all (Carruthers, Dick, & Saurkar, 2005). For the improvement of the weaknesses (e.g., excessive greenhouse gas emission, traffic congestion, unscheduled services) associated with particularly poor public transport, most governments globally try to develop sustainable public transport strategies. Such sustainable strategies have been able to reduce the weaknesses meanwhile providing quality service to the people (Transportation Association of Canada, 2007). According to Ford, Barr, Dawson, and James (2015), also these sustainable strategies have led to the emphasis on the importance of accessibility for economic development, reduction of carbon emission from motorized transport, and provision of transport means for all urban population. However, public transport which is supposed to serve the demand of all population appears not being accessible to disadvantaged people (Lättman, Friman, & Olsson, 2016).

1.2. Research justification

Sustainable public transport strategies have been developed since the 1970s (Wright, 2002). One of the popular and cost-effective approaches to implement particularly in developing countries is the Bus Rapid Transit (BRT). BRT was first implemented in Curitiba-Brazil, later in Bogota-Colombia, Rio de Janeiro-Brazil (Wright, 2002) and in recent decades adopted across many Asian and African cities. According to Nkurunziza, van Maarseveen, and Zuidgeest (2013), BRT has unique characteristics that distinguish it from conventional local buses, which include segregated bus lanes, safe and comfortable terminals, off-board fare collection and regular schedule operations. BRT like other public transport systems has been developed and adopted in cities to mitigate carbon emission as well as to enhance urban mobility such as accessibility to opportunities and reducing inequity based on accessibility. Its success, however particularly in promoting equity based on accessibility depends on the service coverage to enhance the accessibility of people to the service itself and available urban opportunities (Ahmed, Lu, & Ye, 2007).

Equity generally is defined from three pillars of sustainable development (i.e. economic, social and environmental dimensions) as an overlap between social and economic dimensions (Venter, Jennings, Hidalgo, & Valderrama Pineda, 2017). It concerns with fairness in the distribution of wealth, opportunities, and privileges within a society. According to McCahill and Ebeling (2015) equity in sustainable public transport strategies is defined in four dimensions which include accessibility, affordability, health and safety (i.e., exposure to the pollutant, the risk of death), and procedural equity (i.e. delivered service should include interests of different groups).

In recent decades, accessibility is a primary dimension which often used to evaluate transport strategies (Bocarejo & Oviedo, 2011; Fan, Guthrie, & Levinson, 2012). It expresses an easenes or difficulties to reach socio-economic activities/ services/opportunities (jobs, education, health facilities, etc.) by all socio-economic groups. For individuals to participate in daily activities, it highly depends on their mobility levels either to either compulsory or non-compulsory activities, which influences quality of life and improves well-being of individuals (Shah & Adhvaryu, 2016). Public transport provision, therefore can improve mass mobility and hence accessibility in urban areas where there is a diversity of socio-economic groups.

There has been an increasing consideration of equity aspects in sustainable public transport strategies as a long-term objective (El-Geneidy, Levinson, Diab, Boisjoly, Verbich, & Loong, 2016). The aim is to ensure fair distribution of transport resources across all population groups. The implementation of BRT is pro-poor strategy to promote fairness in transport and its inherent political process often linked with poverty alleviation agenda to improve the accessibility of people to services (Jennings, 2015). BRT in developing cites is often found in urban areas with a high level of income disparity, poor spatial land use arrangement and informality (Venter et al., 2017). Equity aspect in BRT system can be evaluated by focusing on accessibility impacts of the system to include marginalized urban groups who are likely to be transit dependents (Pereira, 2018; Karner & Niemeier, 2013).

The use of transport accessibility measures to assess the impacts of public transport such as BRT system has helped the planners and decision makers to understand the integration of land use and public transport as well as equity of transport benefit spatially (El-Geneidy et al., 2016). Jaramillo, Lizárraga, and Grindlay (2012) developed accessibility theoretical framework and index of social transport needs for the city of Santiago de Cali in Colombia. The index was compared with transport provision index of BRT and highlighted the difference between need and supply. They conclude that the BRT system needs some specific measures (e.g., lower fares for low-income earners, service adapted for disabled, extending BRT lines) to include many disadvantaged users. El-Geneidy et al. (2016) described the operation of public transport including the BRT system to assess the social disparity in Montreal city in Canada. They tried to investigate the effect of travel time and cost fare to accessible jobs for marginalized people. They concluded that allocating public transport in equitable manner also relates to travel cost because it considers financial affordability. Also, Bocarejo and Oviedo (2011) used accessibility concept to evaluate the equity impact of the new BRT line in city Bogota. They used travel time budget to analyse the accessibility levels of neighbourhoods to different labour market zones. They concluded that the new BRT line could improve the accessibility of socio-economic disadvantage neighbourhoods if it is integrated with other public transport networks and lower fare structure in such neighbourhoods. Although different studies about the BRT system and equity have been done, most of them do not focus in the context of African cities where BRT system is gaining support from donor institutions with the aim of promoting sustainable mobility to enhance accessibility of all socio-economic groups to job locations, especially the poor (Venter et al., 2017). Therefore, this research seeks to focus on the case of Dar es Salaam city in Tanzania, to understand the relationship between BRT system and equity based on accessibility.

1.3. Research problem

In many African cities, the public transport service is provided by private minibus transport system at affordable prices at least for all urban residents (Venter et al., 2017). The service in many cities is characterized by unscheduled service, poor vehicle condition, traffic congestion, and excessive carbon emission. These characteristics compelled some cities in Africa since 2008 to introduce the BRT system as an alternative means of improving public bus transport system (Venter et al., 2017).

Just like other cities in Africa, Dar es Salaam in Tanzania has started the implementation of a BRT system branded as Dar es Salaam Rapid Transit (DART) to improve its public transport system within the city. It is popularly known to be the fifth BRT system to be implemented in Africa after Lagos (2008), Johannesburg (2009), Cape Town (2010) and George-South Africa (2015). The DART system has six implementation phases. The first phase which is already implemented started operation in 2016. According to DART (2014), by 2035 the implementation of the DART system would be completed along all major road corridors of Dar es Salaam. The routes of the DART system are expected to replace the current public bus transport routes which are currently served by minibuses (Daladala). The DART system has the potential to affect the mobility and accessibility to activities of urban residents who presently depend on minibuses since its operations differs from the minibuses.

Dar es Salaam which is populated with different socio-economic urban population (Ahferon, 2009) who mostly depend on public transport to access their daily activities especially jobs (DSM City Council, 2008; Mfinanga, 2012). With the introduction of the DART system as a new complementary public transport system may affect the spatial accessibility of urban residents to public transport service and job locations which are widely dispersed across the space (Kiunsi, 2013). The proposed DART system aims to provide equitable access to transport service for all urban residents and also improve access to other opportunities (Venter et al., 2017). However, studies emphasized that little is known about BRT system in promoting equitable accessibility to job locations in the Global South cities, particularly African cities. The impact of the proposed DART system in promoting equity based on accessibility to job locations for all socio-economic groups close to the proposed DART network is yet to be studied. It is in this light that, this research aims to evaluate the likely future impact of the proposed DART system in promoting equity based on accessibility to job locations for all socio-economic groups within the city of Dar es Salaam.

1.4. Research objectives and questions

1.4.1. General objective

This research aims to evaluate the equity based on accessibility to job locations across the socio-economic groups who are within walking distance to the proposed DART system. In order to enhance equity within the Dar es Salaam city, possible residential areas are explored for the DART system extension.

1.4.2. Specific objective

i. To analyze accessibility to job locations for socio-economic groups who are within walking distance to the proposed DART system.

ii. To evaluate the equity level of socio-economic groups based on accessibility to job locations.

iii. To explore possible residential areas where the proposed DART system could be extended to enhance equity based on accessibility to job locations.

1.4.3. Research questions

Objective i: To analyze accessibility to job locations for socio-economic groups who are within walking time to the proposed DART system.

a) What is the service area of the proposed DART system, and the population that can be served within walking time?
b) What is the number of accessible job locations for each socio-economic groups who are within walking time to the proposed DART system?

Objective ii: To determine the degrees of inequity based on accessibility to job locations across socio-economic groups.

a) What is the degrees of inequity based on accessibility to job locations across each socio-economic groups?

Objective iii: To explore possible residential areas where the proposed DART system could be extended to enhance equity based on accessibility to job locations.

a) Which residential areas are unserved within walking distance to the proposed DART system?
b) Which residential areas the proposed DART system could be extended to enhance equity level based on accessibility to job locations?

1.5. Conceptual framework

As the significant part that influences the research outputs (Hong, Jiang, & Yin, 2018), the conceptual framework of this research describes the relationship between accessibility and equity concepts in public bus transport (Figure 1.1). Three key elements, i.e., residential locations, job locations and public bus transport (DART system) play an important role in evaluating the equity of BRT system based on accessibility. All elements both have spatial and non-spatial interactions with each other. In this research, the accessibility of urban residents to job locations is operationalized by considering the residents who are within the service area (by walking) of the BRT system because in most cases the BRT system is expected to have a high benefit to those residents proximity to it by walking. The service area provides the general picture of how the BRT system is proximity by walking to residents, and accessibility to job locations describes how well the BRT system is integrated with urban land use. The accessibility to job locations can be evaluated to realize the equity goal (i.e., fair distribution of accessibility impacts between individuals or groups) of the proposed DART system and provide valuable feedbacks to transport planners and policymakers about future public bus transport planning in Dar es Salaam.

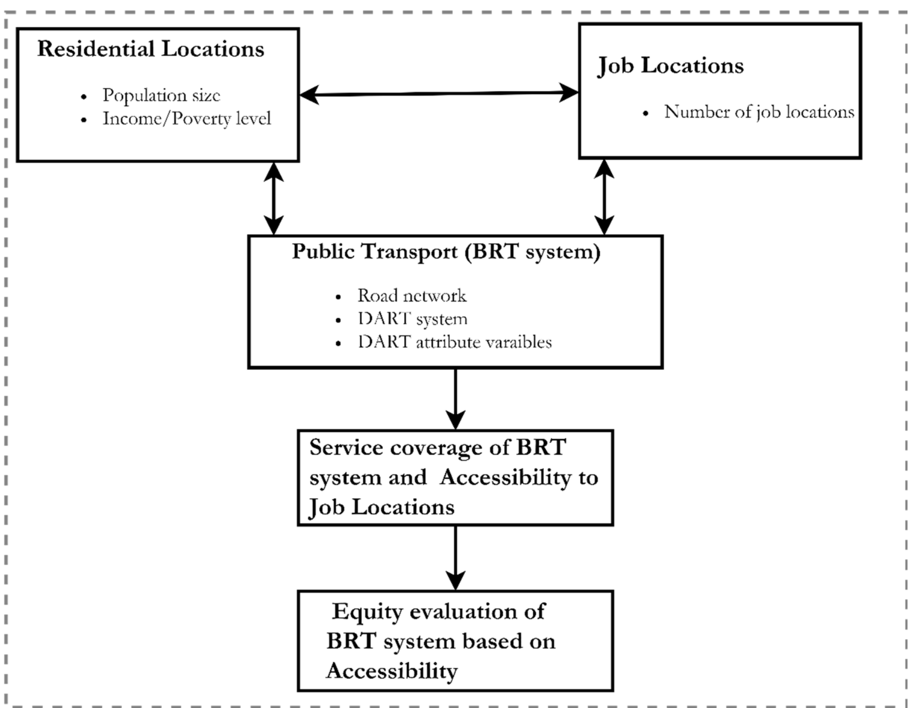


Figure 1-1: Conceptual Framework

1.6. Thesis structure

This research has five chapters. Chapter one which is about research identification presents the background and justification of the study, research problem, objectives and questions. Chapter two presents a literature review of relevant concepts of the study. Chapter three describes the research design and comprehensive methodology applied to the research. Chapter four presents the results of analysis and discussion of findings basing on the specific objectives of the study. Finally, chapter five provides a conclusion and recommendation of the study. A general graphical representation of the entire research process is shown in Figure 1.2.

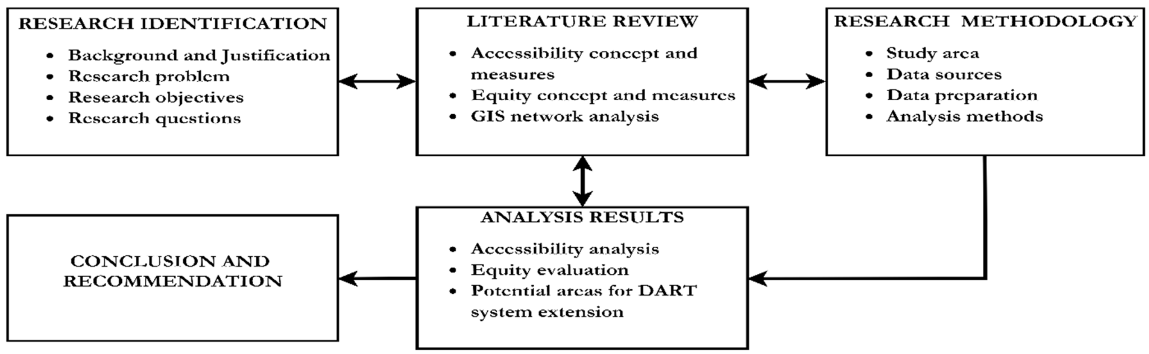


Figure 1-2: Thesis structure

Research design matrix

Main Research Objective: To evaluate the equity based on accessibility to job locations across the socio-economic groups who are within walking distance to the proposed DART system. In order to enhance equity within the Dar es Salaam city, possible residential areas are explored for the DART system extension.

Specific Objectives	Research Question	Method	Data Required	Anticipated Results
i. To analyze accessibility to job locations for socio-economic groups who are within walking distance to the proposed DART system.	a. What is the service area of the proposed DART system, and the population that can be served within walking distance? b. What is the number of accessible job locations per socio-economic groups who are within walking distance to the proposed DART system?	GIS-network based on service area. GIS-network based on OD Cost Matrix Statistical analysis	Transport datasets. Socio-economic datasets. Job location dataset.	The service area of the proposed DART system by walking. Population served within walking distance. Number of accessible job locations for each residential group.
ii. To determine the degrees of inequity based on accessibility to job locations across socio-economic groups	a. What is the degrees of inequity based on accessibility to job locations across each socio-economic groups?	Statistical analysis		Lorenz curves and Gini-coefficients/indices.
iii. To explore potential areas where the proposed DART system could be extended to enhance equity based on accessibility to job locations.	a. Which residential areas are unserved within walking distance to the proposed DART system? b. Which residential areas the proposed DART system could be extended to enhance equity level based on accessibility to job locations?	GIS-network based on OD Cost Matrix Statistical analysis	Transport datasets Socio-economic datasets	Possible road(s) for DART system extension.

2. LITERATURE REVIEW

This chapter presents briefly a view of the main concepts related to this research based on existing literature. The chapter has five main sections. The first two sections describe the BRT as a concept in Global south cities as well as in Dar es Salaam. The third section describes the accessibility concept by focusing on the definition of accessibility, accessibility components, accessibility measures and accessibility as a social indicator. The fourth section describes the concept of equity and how it can be assessed in transport planning. The last section describes GIS network analysis.

2.1. BRT system in the Global South cities

The concept of BRT as a transit system proposed by transport planners was initiated in 1974 in Curitiba-Brazil and later in Bogota-Columbia where it has gained wider popularity all over the world as a cost-effective alternative to far more expensive modes of transport to the ordinary person (Deng & Nelson, 2011). Thus the concept of BRT sought to meet the needs of all especially the low-income class to give them the opportunity to commute to reach their job locations as much as possible (Cervero, Sandoval, & Landis, 2002). In the context of Africa, BRT is still at the nascent state and had been implemented in only five cities including Dar es Salaam.

2.2. BRT system as a concept in Dar es Salaam

In Dar es Salaam, like any other city in the Global South, BRT system emerged as an economical transit alternative not only to ease the pressure on already public transport systems known as Daladalas but to provide an opportunity for the low-income earners to reach their job locations (Chengula & Kombe, 2017). DART system which is expected to cover a total distance of 130.3 kilometres, is expected to save 90% of commuters in the city after its full completion which would increase the productivity of labour by the reduction in substantial time spent in traffic jams (Chengula & Kombe, 2017). Its phase one has chalked some success as it recorded waiting time for passengers at stations is reduced to more than 50% along the routes of that phase (Chengula & Kombe, 2017). Construction on the remaining phases is currently on-going to carter for future transport needs of citizens.

2.3. Accessibility

2.3.1. Definition of Accessibility

As defined by Hansen (1959) accessibility is a measure of interaction of potential opportunities. Accessibility refers to the ease (or difficult) of reaching destinations and services. Accessibility captures the effort required to overcome the separation between two land use activities using a particular transport system (Dalvi & Martin, 1976). It usually reflects the utility associated with travelling between two land use activities. Such utility can be perceived or real costs in terms of distance, time, fare, comfort level, reliability, and availability of transport service. Geurs and van Wee (2004) also defined accessibility as an interaction between land use and transport system to enable people to reach and participate in activities using transport modes. Measuring accessibility provides important information that aids to evaluate and monitor the efficiency of the existing or proposed transport system. Such information reflects the performance of the service provided by a transport system connecting with land use.

In the context of this research, accessibility concept is used to analyse the ease of urban residents to reach the transport service as well as job locations using a BRT system. The distribution benefits of accessibility describe the efficiency of the DART system to commute different urban residents to economic activities and hence to improve the quality of life. The cost variable of travel time is used to measure the accessibility based on the DART system.

2.3.2. Components of Accessibility

As identified by Geurs and van Wee (2004) there are four components of accessibility which include land use, transport, individual, and temporal components. In practice, these components two or more can be combined to measure accessibility.

The land use component reflects the spatial arrangement of land use, and it consists of origins and destinations. Destinations are where the numbers of opportunities such as jobs are supplied. Origins are where the demand for the opportunities (residential areas) are located. Both origins and destinations are presented as point locations or zonal polygons, and their numbers in the study area depend on the scale of analysis (Cheng & Bertolini, 2013). For instance, if the accessibility analysis is at the individual levels, a point represents one person (origin) and job location as a destination. When the scale of analysis is at a larger level, the aggregation of some points (e.g., at the block level, track) is computed firstly.

The transportation component describes the transport network as a disutility for individuals to cover the distance between origin and destination using a particular transport mode. Disutility's are travel time, travel fare and level of comfort. In measuring accessibility, transport network (e.g., roads) is a key point of computing disutility. However other researchers use Euclidian distance to compute disutility, this always does not represent the reality (Nicholls, 2001; Zhen, 2013).

The individual component reflects the socio-economic characteristics of individuals to access the transport mode and spatial distribution of opportunities. Such characteristics include needs (e.g., depending on income, age), abilities (e.g., availability of transport mode, the physical condition of users) and opportunities (e.g., depending on a travel budget, education of users) of individuals.

The temporal component reflects the temporal constraints on both origin and destination. It focuses on different times available for an individual to participate/ reach the destination and different times available for the destination to be accessible.

2.3.3. Measures of Accessibility

According to Geurs and van Wee (2004), there are four basic perspectives/approaches on measuring accessibility that include; infrastructure-based measures, activity-based measure/location-based measures, utility-based measures, and person-based measures.

Infrastructure-based measures/Network connectivity measures analyse the efficiency of the transport network by focusing on the travel impedances (travel time, speed, etc.) and congestion level on the road network. These measures provide information on the service level of the transport infrastructure. Although the measures are easy to operationalize (e.g., needed data can be available, and the results are understood to the decision makers) but they do not consider the travel behaviour of travellers, temporal constraints, and spatial distribution of activities, i.e., land use.

Activity-based measures/location-based measures analyse the accessibility level at locations to the available spatially distributed opportunities/activities with respect to time. These measures are often used in urban planning and geographical studies. Commonly activity-based measures include cumulative/contour-opportunity measure, potential measure, and competition-based measure.

Cumulative-opportunity measure analyses the accessibility at locations by estimating the number of opportunities that can be reached within a specified travel cost (e.g., time, distance). For instance, the number of accessible jobs from origin locations within 30minutes travel time. The measure is not complicated to compute as it does not require information for the travel behaviour of people. Also, its results are easy to understand since it accounts for all destinations equally. The disadvantage of this measure doesn't account for travellers' time perceptions and competition effect at origin and destination (Ben-Akiva & Lerman, 1979).

Potential measure/gravity measure analyses the accessibility level at locations by taking into account the probability of destinations to be reached. The probability is derived from travellers' behaviour using distance decay function and is used to weight the opportunities located in an area (Geurs & van Wee, 2004). Unlike the cumulative measure, the potential measure does not regard all opportunities are equally accessible from the origin by considering impedance and attraction of destinations. The measure is not easy to interpret, and the intrazonal potential has an impact on the potential values (Geertman & Ritsema Van Eck, 1995).

Competition-based measure analyse accessibility at locations by incorporating competition factors at origins and destinations. The measure accounts for imbalances in the spatial distribution of activities by examining the origin sides (e.g., workers) compete for each other for destinations (e.g., jobs) and destinations (e.g., employer) compete for each other for origins. The measure gives a more realistic picture of accessibility by considering both demand and supply sides, but its results are not easy to interpret (Cheng & Bertolini, 2013).

Utility-based measures analyse the accessibility based on how individuals perceived utility for different travel choices. The measures evaluate the derived benefit individuals can gain from accessing spatially distributed activities. However the measures meet the theoretical criteria of accessibility as described by Ben-Akiva and Lerman (1979), it is difficult to operationalize because of high data demand.

Person-based measures/Space-time measures analyse the accessibility at an individual level by integrating spatial and temporal aspects. The measures focus on an individual's freedom of action to participate in activities in a given time (i.e., the time available for an individual to participate in an activity is considered as a constraint). Although the measures meet theoretical criteria of accessibility as described by Ben-Akiva and Lerman (1979), it is difficult to use it at a large geographical scale.

Additionally, according to Joseph & Phillips (1984), the discussed accessibility measures above can be distinguished as potential/physical accessibility measures and revealed accessibility measures. Potential accessibility measures assess the physical access to services or opportunities in term of nature and pattern over space. They depend only on the relative location of demand/origin (e.g., population) and supply/destination (e.g., services or opportunities) and do not involve their actual interaction apart from travel time and or distance. They just assess the availability of services/opportunities moderated by space. Revealed accessibility measures on another hand try to overcome the weakness of the former one by considering the actual interaction between demand and supply sides.

The above subsections briefly explain types of measure and components of accessibility. But the selection of accessibility measure to be calculated/modelled in transport analysis is a subjective decision and depends on the goal of the research and availability of data (Albacete, 2016). In this sense, this research uses land use components (residential and job locations), transportation components (road and DART networks), and individual components (deprivation level of residents) to analyse accessibility of urban residents since it is possible to get data with such components. Also, the activity-based measure was used because it is often applied in urban planning studies (Geurs & van Wee, 2004). Gravity measure is appropriate to use as it provides a proper measure of accessibility between transport and land use interaction (Hansen, 1959). However, the results of this measure are harder to interpret and communicate with stakeholders. Hence cumulative measure, apart from not satisfy most of the accessibility theoretical criteria was applied since it can be used interchangeably with gravity measure due to their high correlation in interpretation (El-Geneidy & Levinson, 2006; El-Geneidy, Cerda, Fischler, & Luka, 2011).

2.3.4. Accessibility as a social indicator

In rare cases, accessibility is used to measure the well-being of urban dwellers. The means for easy reach to different land use functions, which influence social life, is determined by ease of access. Moreover, the number of these destinations reached portrays improved society. Access to work, health services, market, education services, recreation, and other social and economic potentials determine the life of societies. Remote areas face difficulties especially regarding services mentioned above (Halden, Jones, & Wixey, 2005). In urban context inhabitants themselves, determine facilities they demand because opportunities tend to be scarce and unevenly distributed. On the other hand, the spatial organization of facilities and services follows the social and political status of groups mostly provide favour to some wealthy neighbourhoods (Knox, 1980).

It has been an important regard to the government and other private authority to ensure budget for accessibility. This is because the project developed for social and economic purposes should have easy reach. There are many influencing factors, which are both social and economic that push the development of the transport system. For instance, the increased population and economy create the need for a wider range of accessibility including regional highway networks, urban motorways, and rapid transport system (Knox, 1980).

2.4. Equity

2.4.1. Definition of Equity

It is important to evaluate equity in transport planning in order to understand the distribution of benefits over a geographical area (Foth, Manaugh, & El-Geneidy, 2013). Equity describes the fairness with which the benefits of the transport intervention (like the BRT system) are distributed to the different socio-economic groups (Venter et al., 2017). Equity evaluation of public transport planning can be operationalized by measuring the accessibility levels of socio-economic groups. As defined by Lucas, van Wee, and Maat (2015) two types of equity are often defined in transport planning that is horizontal and vertical equity as discussed below

Horizontal equity is based on the notion that transport distribution benefits are not favouring one individual or group over others (Litman, 2018). It just focuses on the spatial distribution of transport benefits regardless of any groups or individuals. Each group gets what they pay for and pay for what they get from fees and taxes unless there is a certain kind of subsidies guaranteed (Litman, 2018).

Vertical equity is based on the concept that considers both the spatial distribution of transport benefits between population groups and compares such benefits across socio-economic groups, for example, vulnerable and marginalized groups. The vertical equity is interested in order to improve the inability among socio-economic groups to access the services, opportunities and goods (Jennings, 2015; Jones & Lucas, 2012)

Litman (2018) describes population categories on which equity can be judged in public transport planning. Such categories include population or activity density of traffic zones that focus on horizontal equity. On these categories, the traffic zones with high density represent the high demand for public transport service. On another hand, car ownership, income levels, age groups, ethnicity and deprivation levels focus on vertical equity as they related to the fairness of public transport supply. This type of equity is viewed in two dimensions as briefly explained below.

Vertical equity with regard to income and social class: This is also known as social justice and social inclusion which concerns with the distribution of impacts between groups that are heterogeneous either by income or social class. This looks transport policy to be equitable if it favour socially and economically disadvantaged groups as a way of compensating for overall inequities (Litman, 2018). This type of equity calls for support of mode improvements, special services and offering of a discount for lower income groups and extra efforts are being made to ensure that the less advantages do not bear excessive external costs.

Vertical equity with regard to mobility and need: This concerns with the distribution of impacts between which have different mobility ability and needs, the extent to which transportation system meets the specific needs of commuters with mobility impairments. It accommodates all users including ones with special needs.

2.4.2. Equity in BRT

BRT as a public transport system contributes to social justice and social sustainability in the cities of Global South. It also serves a mechanism of promoting socially sustainable mobility, and it has been acknowledged to improving urban mobility through interventions such as busway improvements, efficient scheduled operations, and betterment of the urban environment (Cervero, 2013). BRT in the Global South is implemented as a pro-poor strategy aimed at alleviating poverty through improvement of access to opportunities and (Jennings, 2015; Jones & Lucas, 2012; Venter, Jennings, & Hidalgo, 2017). Specific examples include the Bogota TransMilenio in Columbia which improved quality of life and provided a better future for citizens (Guzman & Oviedo, 2018). It is also noted that BRT offers substantial benefits to low-income groups, in terms of travel time and cost savings, safety and health benefits as well as access enhancement (Venter et al., 2017). However, it is noted that with the potential of protecting the interest of the poor, it can also lead to their displacement through gentrification as a result of an increase in land values along BRT corridors (Venter et al., 2017).

Again the principal function of BRT as public transport is to provide access to opportunities to all members of society particularly those with limited mobility options (Manaugh, 2010). This brings in and makes equity in public transport paramount. Thus equity in BRT is all about giving the disadvantaged populations the opportunity to have higher accessibility and more mobility options, regardless of their ability to pay. Equity in BRT is to ensure that access is provided to job locations for those with limited mobility choices, which is usually amongst the poor (Sanchez, Shen, & Peng, 2004). Studies have affirmed that there is a correlation between transit use and income status. In this regard, it is evidenced that most often municipalities attempt to service low-density residential growth at the urban peripheries while the inner-city transit dependent on households are not given the same priority (Manaugh, 2010).

Better still, policymakers have asserted that an increase in BRT is capable of positively affecting the employment status of people, especially the low-income ones. It is assumed that BRT can effectively link the unemployed and car-less population with appropriate job locations (Cervero et al., 2002). It is observed that the current patterns of development of most countries in the Global South result into spatial disadvantaged for low-income workers, which BRT has the potential to overcome employment accessibility and mobility problems. However, studies in Atlanta-Georgia and Portland-Oregon proved this relation between public transport like BRT with employment locations but in the city of Dale County- Alabama proved contrary to this analogue (Sanchez et al., 2004).

In this research, the vertical equity based on accessibility is evaluated to understand the project benefits of BRT (the proposed DART system) to least advantaged residents over most advantaged ones since in most cases the least advantaged residents are considered to be more public transit dependants than most advantaged ones. Furthermore, as explain by Marsh and Schilling (1994) the fundamental process of evaluating equity involves a comparison of impact of an action among the individuals who are defined on basis of e.g. income, race, gender etc. In this regard, this research evaluates the job accessibility distribution that would results from the DART system implementation across the socio-economic groups who defined by their deprivation level.

2.4.3. Measures of Equity based on accessibility

To measure or evaluate equity based on accessibility depends on first, the selection of appropriate accessibility measure to meet the goal under study and second, identification of indicators and their level of aggregation (e.g., income levels at individual, the household or census tract) to measure the accessibility distribution across the population groups (Wee & Geurs, 2011). Equity evaluation in public transport planning can be assessed based on accessibility changes or accessibility levels across the population groups

(Ortega, Monzón, & López, 2013). Several mathematical approaches exist and are applied by academic researchers and transport planners to assess equity in transport planning policies. According to Lemans (2016); Jang, An, Yi, and Lee (2017); Rahman and Neema (2015); Tsou, Hung, and Chang (2005); Cao, Liu, Wang, and Li (2013) these approaches are; descriptive statistics (i.e. range, variance and coefficient of variation), Theil index, Palma ratio, Lorenz curve and Gini coefficient, Spatial autocorrelation, Integrated equity index, Spatial auto-regression etc. From these mathematical approaches, low values depict close to perfect equity (equal distribution of accessibility impacts) while high values depict close to inequity. As described by Ortega et al. (2013), there is no common mathematical approach to assess equity in transport planning. But according to Delbosc and Currie (2011), the easy approach to interpret is the Gini coefficient using the Lorenz curve[1]. The approach provides a single value (Gini coefficient/index) that can be visualized on a curve and used to judge the degree level of equity based on accessibility distribution for overall/across population groups. The curve represents the cumulative distribution of accessibility across the population (Lorenz, 1905; Lucas et al., 2015). The Gini coefficient is a mathematical value that represents the degree/level of inequality, and that can provide information about equity (Delbosc & Currie, 2011; Lucas et al., 2015). In the Lorenz curve (Figure 2-1), the Gini coefficient is the ratio of the areas between the equal distribution line and Lorenz curve, and the total area under the equal distribution line. The value of the Gini coefficient is between zero and one. The lower the value, the more equitable of accessibility distribution, and the higher value indicates unequal distribution. The Gini coefficient from the Lorenz curve can be approximated using equation 1.

$$Gini\ coefficient = \frac{Area\ of\ A}{Area\ of\ A + Area\ of\ B} \quad \text{(i)}$$

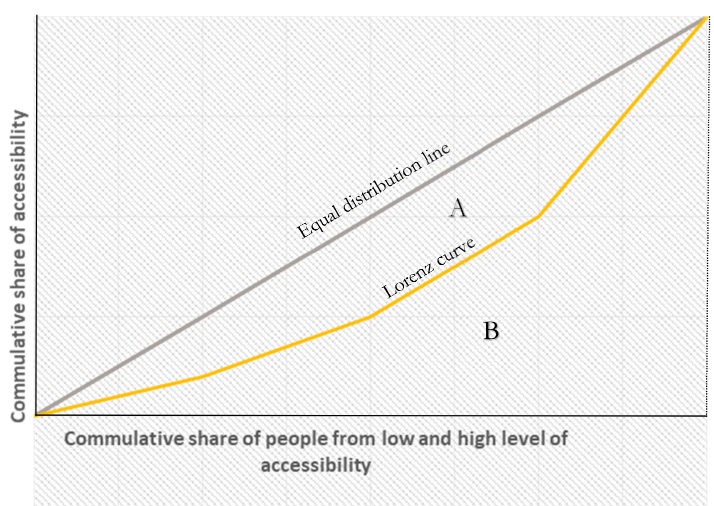


Figure 2-1: Lorenz curve

[1] Lorenz curve is well known in economies and applied to represent the cumulative distribution of wealth/income across the population. The curve also can be used to any quantity that can be cumulated across the population.

2.5. Transport System and GIS network analysis

As defined by Tolley and Turton (1995), the transport system is "the assemblage of components associated with specific means of transport." Such components of the transport system are network, routes, terminals, and nodes. The network is the framework within a transport system composed of routes. The route is a link between two nodes/terminals while nodes/terminals are starting or ending points of the routes and usually act as transferring points where people can switch between the transport modes. Also according to Zuidgeest, Brussel, Arora, Bhamidipati, et al. (2009), the transport system is the combination of subsystems of transport whereby each subsystem is representing a specific transport mode and is composed by transport components. From this perspective, the transport system is considered as multimodality system in nature as it involves the connection of more than one transport mode at the terminals/nodes where people/goods can make transfers.

Nowadays due to the availability of transport data, GIS network analysis provides a suitable platform that has the capabilities to model, analyse, visualize and retrieve such data using geoprocessing tools (Mandloi & Thill, 2010). It uses a graph theory approach to store the transport system information in the spatial database as it exists on the earth's surface (Esri UK & Ireland., 2018). The transport system in GIS network analyst is represented by a set of nodes/vertices and links/edges that are interconnected and topologically related. The nodes and links together are used to store travel impedances (e.g., speed, travel time, waiting times at stops, travel fare) that represent the constraints/weight of moving from one location to another using specific transport mode.

Additionally, in GIS network analysis there are different concepts (such as 3D, dynamic segmentation, arc node data model, hierarchical, etc.) for modeling multimodal transport system (Mahrous, 2012). The 3D concept (Figure 2-2) is the most suitable one as it provides a good representation of the transport system with large subsystems without overlapping the components (Musliman, Rahman, & Coors, 2008). The concept physically uses the idea of separating the subsystems (e.g., pedestrian paths and Bus routes) by elevations and connecting one subsystem to another using hypothetical links (dummy) and false stops that carry impedances of transfers from one subsystem to another.

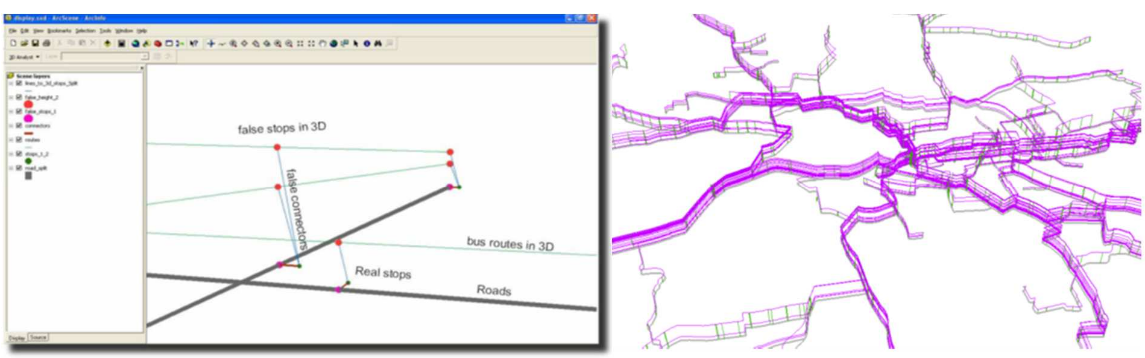


Figure 2-2: Examples of 3D network representation in the GIS environment

3. STUDY AREA AND RESEARCH METHODOLOGY

This chapter presents two main sections; the first section describes the city of Dar es Salaam where the study was carried out and the second section describes the whole methodological approaches deployed to achieve the main objective of this research.

3.1. Study area

This section provides the descriptions of Dar es Salaam city by focusing on its population growth trends, the spatial structure of the city and issues of public transport. Also, the section gives a brief explanation on which part of the city the research was conducted for accessibility analysis.

3.1.1. General description

Geographically, Dar es Salaam city lies along the coastal Indian Ocean at latitude 6.8^{0}S and longitude 39.3^{0}E. Dar es Salaam city is one of the fastest growing cities in Sub Saharan Africa (Clos, 2016), and the largest commercial city of Tanzania. It is a home of the country's core industry and business and contributes 17% of the national gross domestic product (United Republic of Tanzania, 2017). Dar es Salaam is expected to become a megacity before 2030 (Hill, Hühner, Kreibich, & Lindner, 2014).
Administratively, Dar es Salaam city is among the 30 regions of Tanzania. It covers 1,631 square kilometers which is about 0.2% of the total area of Tanzania. The city has five municipalities; Ubungo, Kinondoni, Temeke, Kigamboni and Ilala (Figure 3-1) which subdivided into ten constituencies and 90 wards. According to the population census of 2012, the city has 4.4 million inhabitants (i.e., 10% of the total Tanzania population) and currently it is estimated to have 5 million inhabitants (National Bureau of Statistics Tanzania, 2013). As depicted from Figure 3-2, the population growth of Dar es Salaam is highly increasing, but the spurt in urbanization occurred since 1978. This resulted the city in 2012 to have a population density of 3133 inhabitants/km^2 and sprawling along the major traffic corridors (Oneko, 2017). Like many other Global cities, also rapid population growth has given rise to the city with uneven service infrastructure provision and poor transport connections (Kiunsi, 2013).

Despite the peripheral settlement expansion, spatially the city has a monocentric structure whereby many important facilities are still located in the Central Business District (CBD) (Kiunsi, 2013). The CBD is connected with suburb by five major roads which form the backbone of the city road network. This has led traffic congestion particularly in work-day peak hours (6:30am-9: 30 am and 04:00pm-7:30 am) as many commuters use private and public transport to access/out access facilities (Kiunsi, 2013). To reduce such traffic congestion and improving mobility and accessibility, the government of Tanzania since 2016 has decided to implement the BRT system. According to DART (2014) and DSM City Council (2008), the BRT system in Dar es Salaam would help to reduce traffic congestion and commuting time particularly to and from the transit dependent communities.

In this research, the area of 20km from CBD has been selected to be the case study area (Figure 3-1). It is the urban zone of Dar es Salaam city and approximately covers 524 square kilometers. Administratively the area is comprised of 73 wards[2] and is where all phases of the proposed DART system will cover by 2035. The area is densely populated (Figure 3-3) and characterized by different socio-economic groups. The area has connected with public bus transport routes to serve public transit dependents (Mkalawa & Haixiao, 2014). Also within this area, at least enough spatial data for transport networks, job locations, and socio-demography were available for accomplishing this thesis.

[2] Wards are fourth-level of administrative divisions in Dar es Salaam

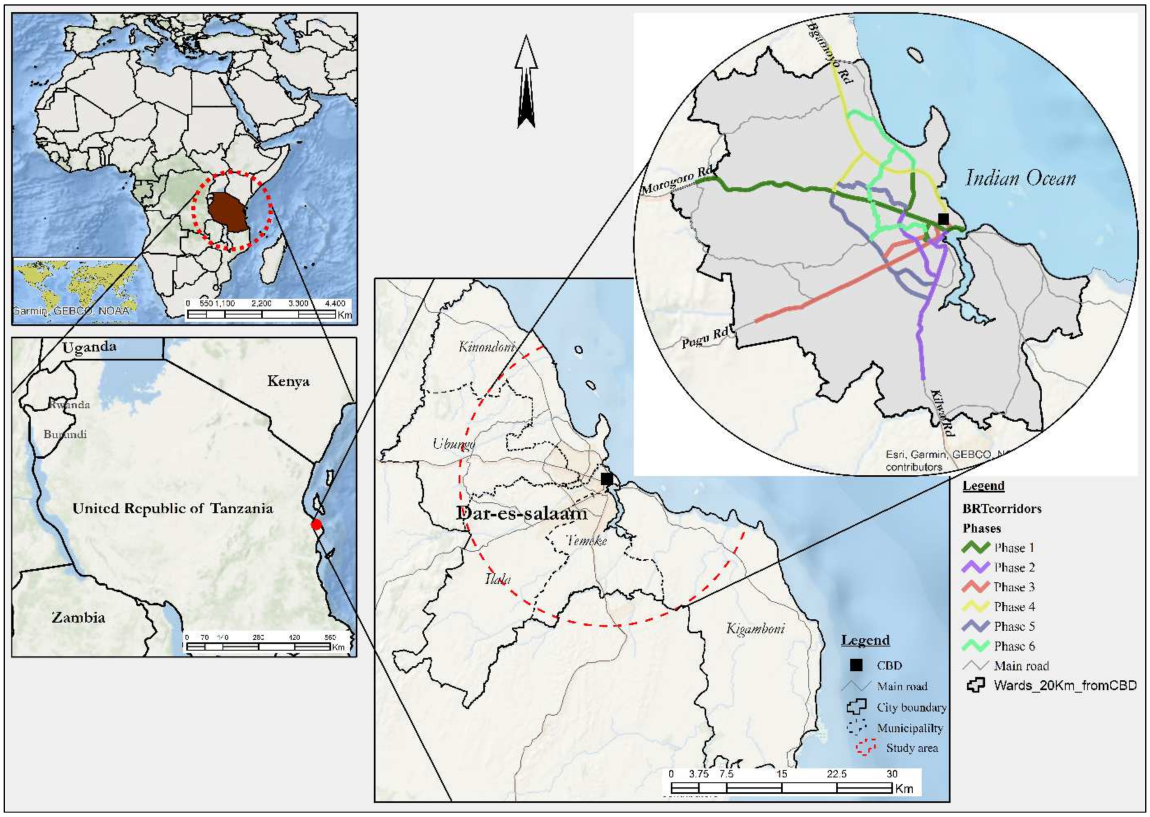
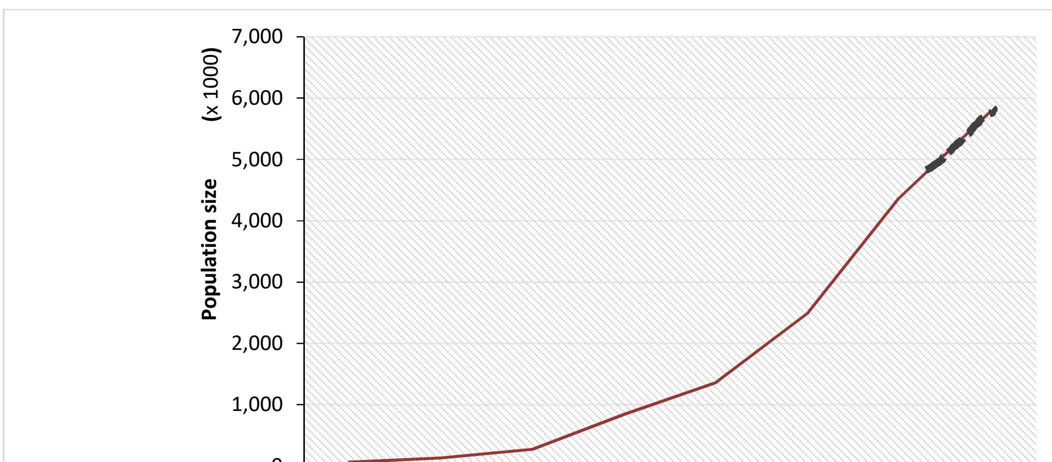


Figure 3-1: Location of the study area.



	1948	1957	1967	1978	1988	2002	2012	2018
Population	62,227	128,742	272,821	843,090	1,360,850	2,487,288	4,364,541	5,781,557
Population growth rate		7.40%	7.80%	9.88%	4.59%	4.84%	5.60%	5.70%

Figure 3-2: Absolute and relative population growth of Dar es Salaam.
Note: Population of 2018 is an extrapolation done by UN-Habitat
*Source: (*Sheuya, 2010*; National Bureau of Statistics Tanzania, 2013)*

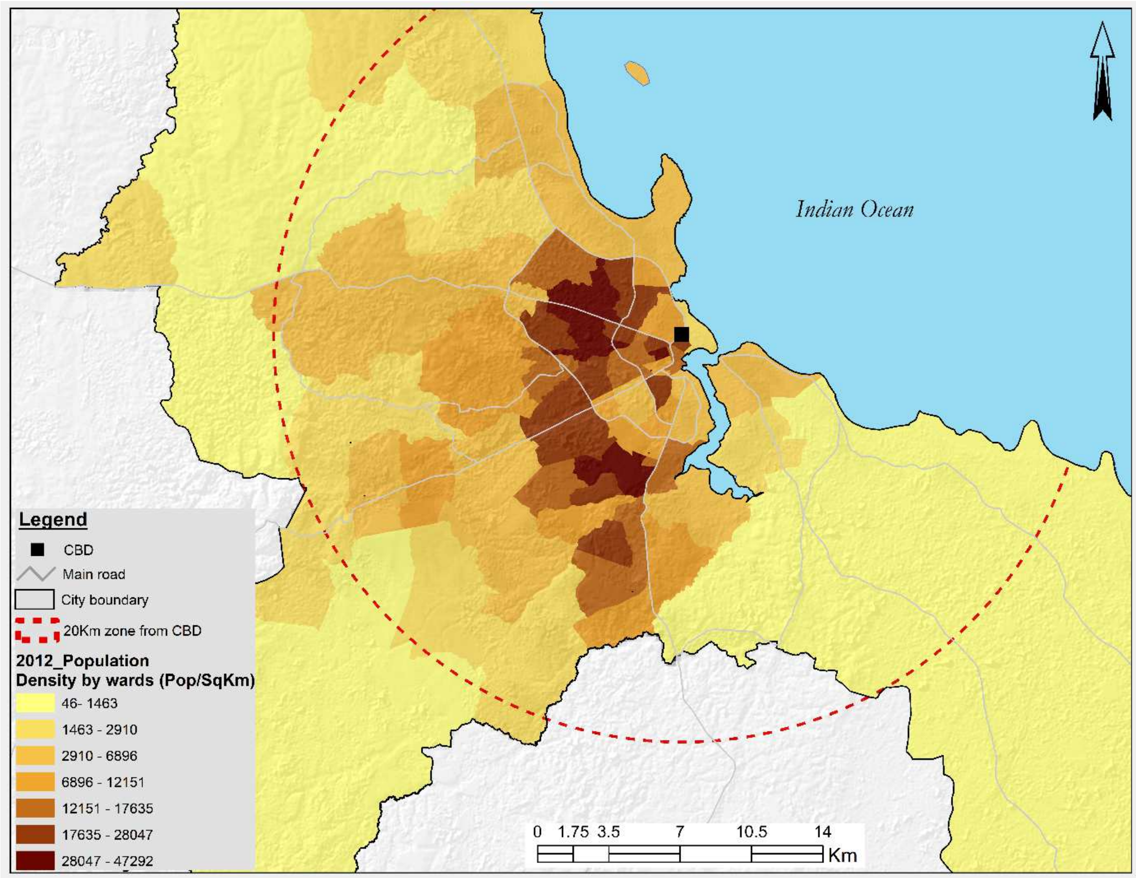


Figure 3-3: Population density by wards of Dar es Salaam 2012.
Source: (National Bureau of Statistics Tanzania, 2013 and modified by author)

3.1.2. A general overview of the current public transport system in Dar es Salaam

Dar es Salaam, the most populated and major commercial city in Tanzania, has very developed transport networks that connect with other major cities in neighbouring countries such as Nairobi (Kenya), Kampala (Uganda), Kigali (Rwanda), and Lusaka (Zambia) (Dar es Salaam City Council, 2008). For public transport, Dar es Salaam city has a commuter railway, ferry, and bus transport that connect different parts of the city. It is the main mode of transport system having a high share of users however traditionally not of high quality (World Bank, 2017).

Commuter railway was introduced in 2012 and operates along TAZARA and TRL rail lines (Figure 7). The service is provided in working days at peak hours (i.e., 6:00- 10:20 am and 15:55- 22:15 pm) between Posta, Ubungo, Pugu, Tazara and Mwakanga bus stops (Dar es Salaam City Council, 2018a). Now there is the construction standard gauge rail that will provide service to the commuters in neighbouring towns.

The ferry service is found at Kivukoni area. It provides accessibility of commuters to Kigamboni suburban area. The service is available for 24 hours. Kigamboni area also can be accessed through the Kigamboni Bridge that was constructed in 2016.

According to DSM City Council (2008) and DART (2014), public bus transport approximately covers 25% of road networks. It operates under mixed traffic with private vehicles and motorcycles except for the BRT buses that operate in segregated lanes (Appendix 1). The public bus service is found mainly along the trunk and main collector roads (Figure 3-4). Currently, the public bus transport service is provided by paratransit minibuses (called daladala) and BRT buses. Most paratransit minibuses are owned by private people while

BRT buses are under government agency called DART/UDA-RT (Dar es Salaam City Council, 2018b). The BRT service was proposed by the government of Tanzania in collaboration with Word bank with the significant aim of reducing commuting time in the city. The BRT service was launched in 2016 and was planned to have six phases (140.1 km of corridors) by 2035. Currently, only BRT phase-1 is under operation as a pilot project while phase-2 and 3 are under evaluation stage to start implementation by 2020. BRT phase-1 has 21 km trunk corridor, 27 bus stops and 5 terminals (Appendix 2). The service operation time for BRT is 5:00 am to 12:00 am (midnight) while for daladala is nearly 24 hours even though the regulation allowed them to operate from 5:00 am to 23:00 (Dar es Salaam City Council, 2018a).

Rules and regulations for insisting order and safety in public transport are set by SUMATRA (i.e., Government authority for managing surface and marine transport). SUMATRA issues annual licenses to public transport operators in particular routes and instructs the amount of fare per routes. Also, the authority has the power to ensure a competitive quality of transport service in Dar es Salaam.

Presently public transport in Dar es Salaam faces issues such as crowded buses and ferry due high demand that not met by service supply, unscheduled service and off information about the service, small coverage of the service particularly in residential areas, insufficient operation that causes traffic jams at peak hours, traffic accidents especially at mix lanes with motorcycle and pedestrian crossing, and flooding of some roads during heavy rain (Dar es Salaam City Council, 2018a).

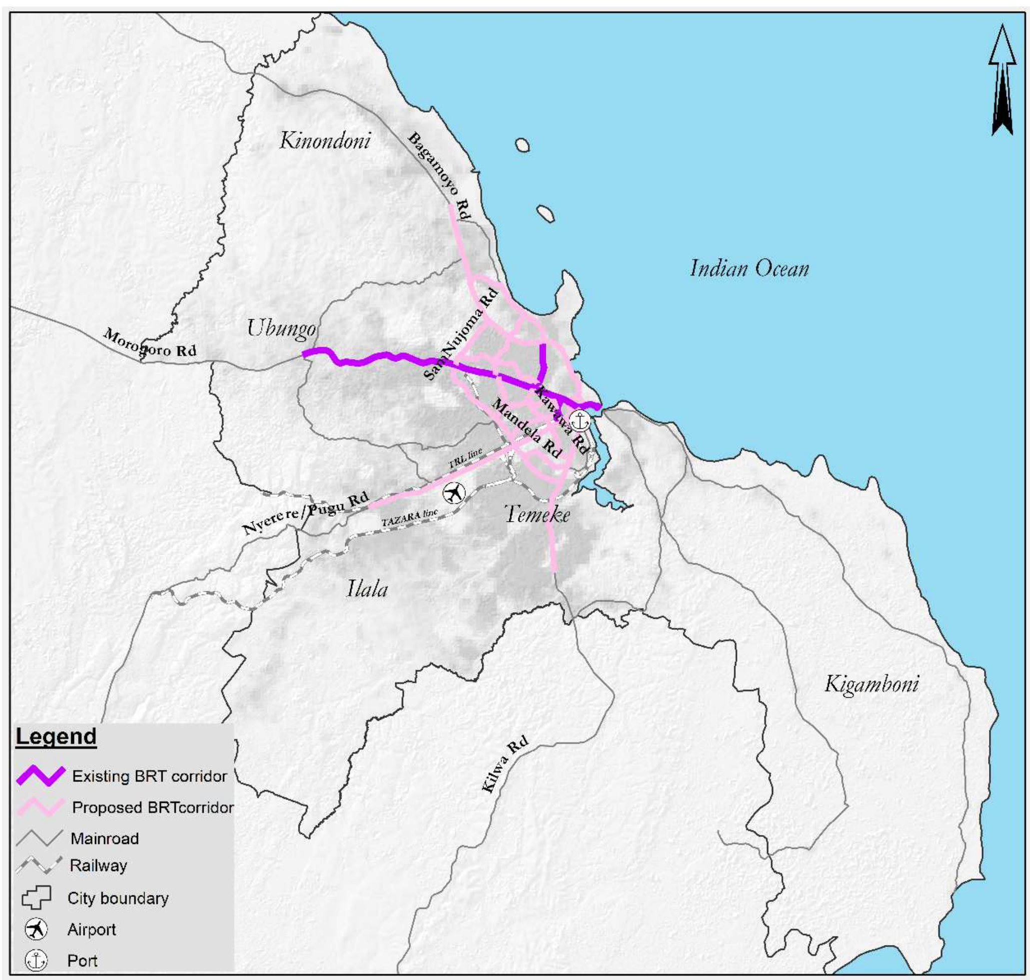


Figure 3-4: Dar es Salaam public transport corridors.
Source: (Dar es Salaam City Council, 2018b)

3.2. Research methodology

This section describes the design and applicable methods for the research to achieve the main objective. It explains datasets, sources, and their preparation before used in the analysis, and also the analysis methods applied for accomplishing specific objectives.

3.2.1. Research approach

In this research, the main research approach employed is a quantitative methodology (i.e., spatial and statistical methods). The whole methodology has been divided into three blocks (Figure 3-5). The first block is about dataset description, preparation, and unit of analysis, the second block; DART system/network modeling in a GIS environment for estimating accessibility and the third block; estimation of accessibility and equity evaluation. In the first objective spatial analysis basically on GIS-network analysis was employed to compute the accessibility of socio-economic groups to job locations via the proposed DART system/network. In the second objective, the equity evaluation was operationalized using a statistical method to measure the degree of variation in job accessibility distribution across socio-economic groups. In third objective spatial and statistical analysis were applied to explore the potential areas where the DART system could be extended to enhance equity based on accessibility for residential areas that are far away from the proposed DART system.

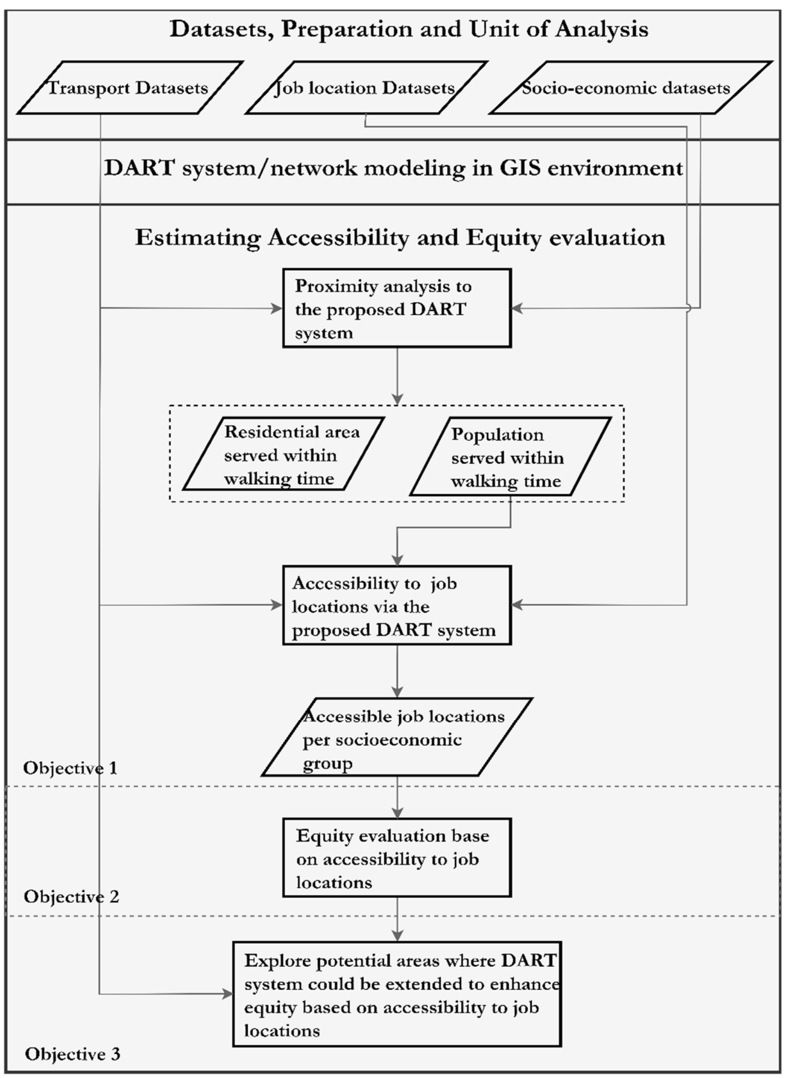


Figure 3-5: Methodological Workflow

3.2.2. Datasets and sources

This sub-section describes all secondary datasets (spatial and non-spatial) which were acquired during the field fieldwork. The datasets acquired and used for analysis are transportation data (i.e., road networks of Dar es Salaam, public transport network for DART system), Job location/workplace data and Socio-economic data (i.e., population counts administrative wards and multidimensional-poverty-index) (Table 3-1)

Table 3-1: Summary of datasets

No.	Dataset	Format	Acquisition date	Source
Transportation data				
i.	Dar es Salaam road networks	Vector (shp)	2018	OSM (https://www.openstreetmap.org)
ii.	Trunk corridors of the DART system	Vector (shp)	2017	DART and SUMATRA offices
iii.	Proposed and Existing BRT stops and terminals	Vector (shp)	2017	DART and SUMATRA offices
iv.	Existing and proposed DART routes	Vector (shp)	2017	DART office
v.	DART's attribute variables (e.g. the speed of the bus, Travel fare per route, Waiting and Egress times at bus stops or terminals)	Excel	2017	DART office
Job location data				
i.	Job locations (financial institutions, retail businesses, academic institutions, industries, public and private offices)	Vector (shp)	2015	TRA
Socio-economic data				
i.	Administrative boundaries of wards	Vector (shp)	2012	TNBS
ii.	Population count	Raster	2015	Worldpop (http://www.worldpop.org.uk)
iii.	Multidimensional-poverty-index	Raster	2013	Worldpop (http://www.worldpop.org.uk)
iv.	Building footprint	Vector (shp)	2018	OSM (https://www.openstreetmap.org)

Source: Author, 2018

3.2.2.1. Transportation data

Dataset of road networks for Dar es Salaam was downloaded from the Open-StreetMap (OSM) website in October 2018. The data included the classification of roads, size, road condition, the name of roads and road restrictions (i.e., one way or not). This data is prepared and updated by Ramani Huria organization through digitizing from UAV-images[3]. The data is disseminated free online with the purposes of sharing the geo-transport network data of Dar es Salaam globally. Routes for commuter rails and paratransit-minibuses were also downloaded from Open-StreetMap (OSM) in October 2018.

Datasets of public bus transport network for the DART system were obtained from DART and SUMATRA offices during the fieldwork in October 2018. The data included the existing and proposed BRT corridors, routes/service lines and bus stops in 2035 and operational attributes for the service. The only bus stops data were acquired in shapefile format while other data in documentary sources which were prepared during the revision of Dar es Salaam transport master plan in 2017. The data about existing and proposed DART

[3] UAV-images are aerial images captured by an unmanned aerial vehicle/drone

routes by phases were extracted from documents through on-screen manual digitizing[4] using Arc GIS software in order to have detailed geolocation information (Figure 3-6). All stops and digitized routes were geolocated with Z-coordinate values so as later in GIS modeling to have separate connectivity between the road network and the DART network. Also, the digitized routes were attributed with operational DART values such as speed of buses and waiting time at stops that were obtained from provided documents. These attribute values were also verified by observing the operation of DART phase-1(which also applies to other proposed phases) while in fieldwork and find out no much differences of values (Table 3-2). The whole steps for preparing DART routes for analysis purpose see Appendix 3

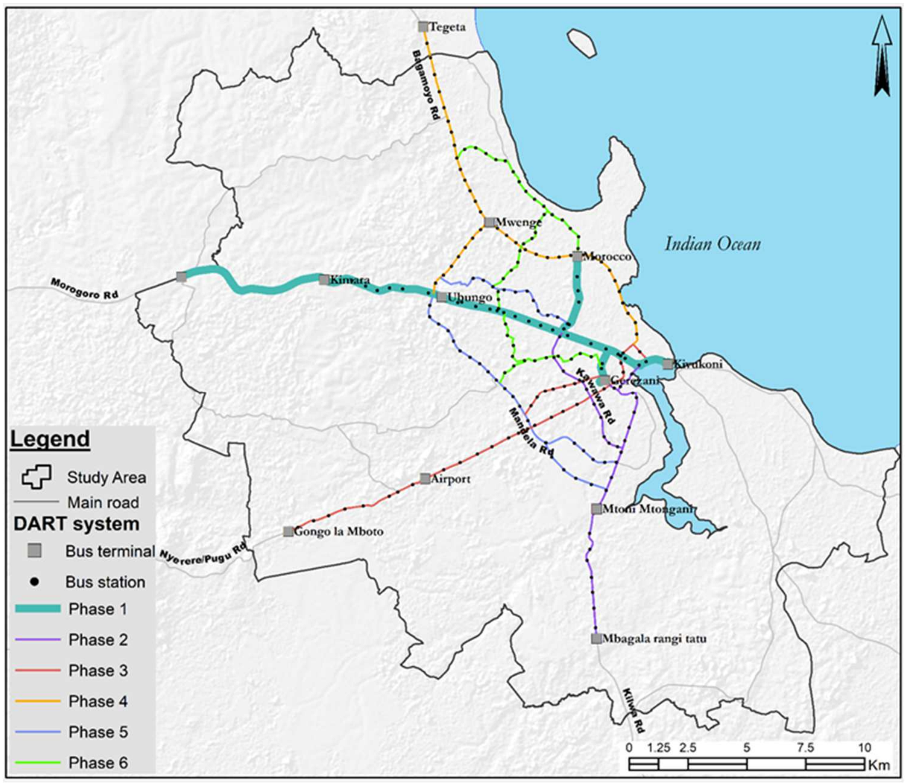


Figure 3-6: Existing (phase-1) and other phases of the proposed DART system

Table 3-2: DART attribute variables for phase-1

	Variable	From the documents	Field observation
i.	Average bus speed	23km/h at peak hours in working days.	25km/h at peak hours in working days. (was measured by taking a route from Kimara stop to Kivukoni stop and recording the time taken and length of the route using google map app. The length of the route was divided by time).
ii.	• Waiting time at the bus stop/operation frequency,	3-minutes interval at peak hours in working days when the operation rate is 100%.	3-5 minute interval at peak hours in working days when the operation rate is 100%
	• Egress time/ Average stopping time at the bus stop	1-minute	1.5-minute

Source: Author, 2018

[4] With the help of downloaded road networks and drawings of DART system from documents, the routes were traced in separate shapefile.

3.2.2.2. Job location data

Job locations dataset was acquired from Tanzania Revenue Authority (TRA) office. The dataset was provided as feature points in shapefile format and included 40,000 formal/registered private and public establishments (Figure 3-7). Due to the confidentiality of the data, the provided data includes only the locational address of establishments and not the number of employment available in each establishment. The dataset was prepared since in 2015 and still under preparation (before the dataset was not in spatial format). Up to the date of data acquisition, the provided job dataset includes most information not more than 20 km from CBD. Also, informal job data was intended to be obtained and used for analysis. But due unavailability of such data, only formal job locations were used for analysis.

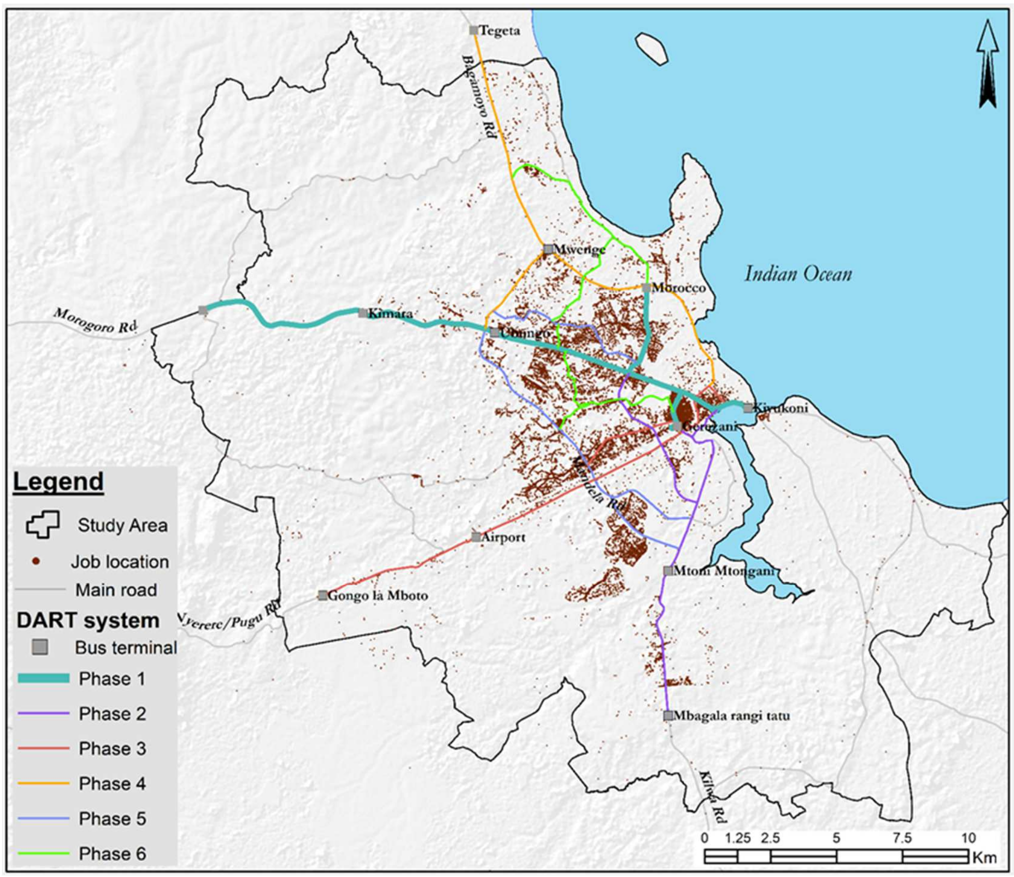


Figure 3-7: Location of job centers/workplaces

3.2.2.3. Socio-economic data

Datasets of administrative ward boundaries were acquired from the office of Tanzania National Bureau of Statistics (TNBS). The data was prepared from population census data of Dar es Salaam 2012. Data was provided in shapefile format.

Before the fieldwork, the average income per capita/income disparity data was proposed to be used for categorizing residential population in order to evaluate equity in transport based on accessibility. Unfortunately, the data was missing, and substituted by multidimensional-poverty-index data for Tanzania (Figure 3-8) which was downloaded from Worldpop-website *(http://www.worldpop.org.uk)*. Multidimensional-poverty-index (MPI) data was in raster format of a 1x1km spatial unit and was prepared in 2013 by University of Southampton/Oxford using Demographic and Health Survey geo-data of Tanzania collected at household levels in 2012. The data estimates the level of national poverty (i.e., the proportion of people per grid square living in poverty) across every location in a country. The data was prepared with the aim of mapping and monitoring national poverty using remoting sensing and geospatial techniques. This data is better than income per capita only for understanding the level of residential disparity as it measures poverty beyond the income-based lists. However, according to Albert and Gaspar (2015), MPI has a strong correlation with income poverty rates with few outliers. MPI is representing health, educational achievement and living standard dimensions that constitute people's experience deprivation (Oxford University, 2018).

Building footprints data was downloaded from the Open-StreetMap (OSM) website in October 2018. This data is prepared and updated by Ramani Huria organization in Dar es Salaam. The data includes the uses of buildings, i.e., residential, commercial, commercial-residential, industries, etc. The data was downloaded with the aim of estimating population number at residential locations by combing it with population data which was also downloaded from Worldpop-website. The population data from Worldpop (in raster format of 100x100m) has estimated population 2015 for whole city Dar es Salaam.

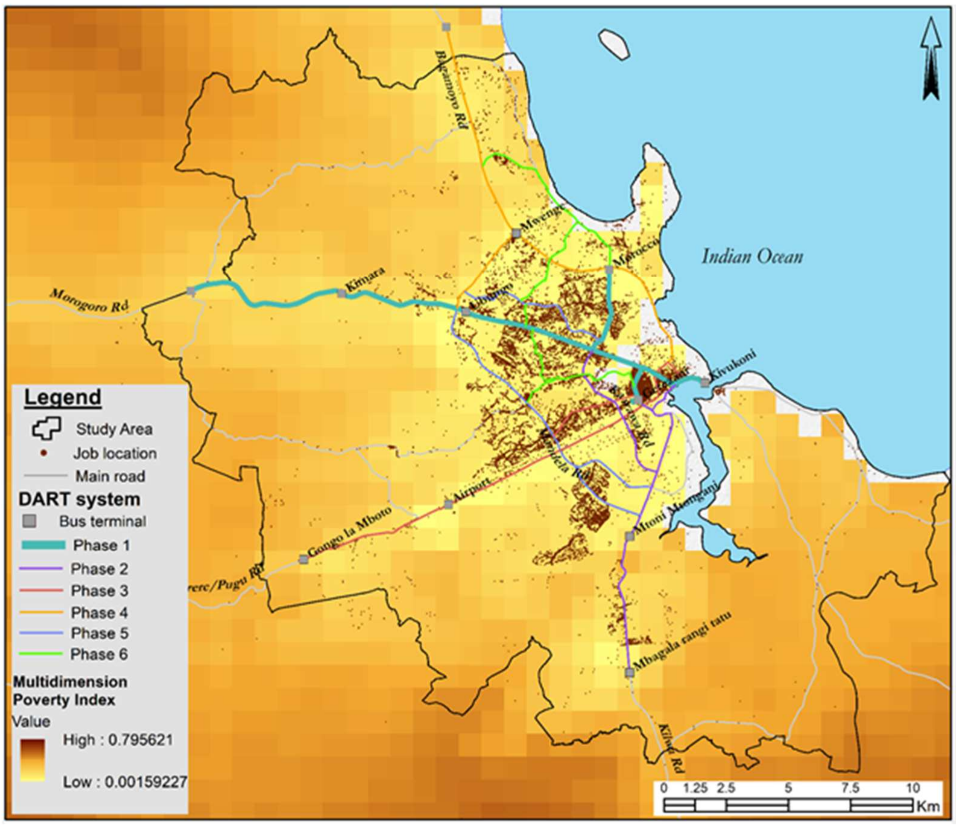


Figure 3-8: Multidimensional-poverty-index of Dar es Salaam (high value represents a high poverty level, and low value represents low poverty)

3.2.3. Dataset preparation and Unit of analysis

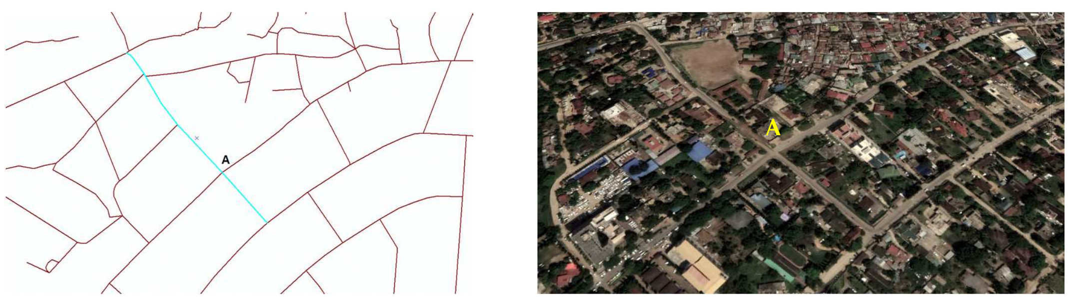
This sub-section describes how the three datasets were prepared for analysis. As this research involves the integration of different datasets, the issues of data integration in GIS was examined since it facilitates further analysis of the data.

3.2.3.1. Transportation data

The road networks data was topologically validated (i.e., checking the consistency of the features). This is because sometimes data from these open sources have potential errors due to voluntary collection and need for users to check, test and correct it before using (Melbye, Møller-Jensen, Andreasen, Kiduanga, & Busck, 2015). Therefore, with the aid of topological rules, all road features which were not/improperly connected were identified (Figure 3-9) and corrected through on-screen manual digitizing so as to have the proper connectivity of roads during network analysis. Another error which was identified from road networks data is some of the road lines at junctions were not digitized as segment lines (i.e. road junctions were digitized as overpass or underpass which is not the real case on the ground) (Figure 3-10). This can affect the results as instead of taking the shortest routes during accessibility analysis; the network will display an error message of no route can be found. The problem was fixed by using the "feature to line tool" in Arc-GIS software and broke every line segment at junctions. Furthermore, for the analysis purpose of this research, the road lines were also broken at each bus stop to provide a connection with DART service lines through connectors. Datasets from OSM usually have a coordinate system (WGS 1984) different from the ones used in many local areas. So in order to ensure the downloaded road networks dataset spatially match with other acquired spatial data from the fieldwork, the data was transformed from datum WGS 1984 to Arc 1960[5] which is used in Dar es Salaam. Finally, the road network dataset was geolocated with Z-coordinate values so as to have separate connectivity from the DART network.

(i) (ii)

Figure 3-9: Example of identified road junction at "X" (using ArcGIS software) not connected/undershoot (i), and its reality on the ground (ii)



(i) (ii)

Figure 3-10 Example of identified road junction at "A" (using ArcGIS software) not digitized as segment lines (i), and its reality on the ground (ii)

3.2.3.2. Socio-economic data

The study area was disaggregated into hexagonal grids of 250 by 250 meters as the unit of analysis in order to model the public transport accessibility via the DART system in high resolution without compromising computational tractability. However this technique slow the computation speed during the modeling. The 250 by 250 meters hexagons were used because in the study area the population density is relatively high and road network information are a lot available. The 250 by 250 meters hexagons would then increase the

[5] In this research all maps were prepared using Arc_1960 datum together with the projection of _UTM_Zone_37S

quality of accessibility results instead of using administrative wards (whose relative size is large) as the units of analysis. Additionally, the hexagonal grids were used instead of rectangular grids since they minimize sampling bias from edge effect and are suitable for analyzing spatial phenomena in which nearest neighbourhood and connectivity are important (Birch, Oom, & Beecham, 2007).

Then the hexagons were populated with population counts data by adopting the approach of Martin (2015) whereby population counts at administrative units are distributed at building levels instead of using convention approach of population density. The approach of Martin (2015) assumes uneven population distribution within the defined administrative units because in reality population is more or less spatially clustered. Although the approach of Martin (2015) in some way appropriate but is limited to the availability of building footprints data, and it has complicated computation. The downloaded population data from Worldpop was used to populate the hexagons. However, the data has a challenge of having 100x100m resolution. So to combine it with residential building footprints could lead buildings within 100x100m to have the same population count and hence lead to overestimation of the population. By using the administrative ward boundaries of 2012 and population data from Worldpop, the population of 2015[6] at ward levels were firstly estimated by extracting the values from this population data. The estimated population counts were then disaggregated into hexagons using building footprints. The following are the steps used to disaggregate the estimated population counts into grids using building footprints. Also, Figure 3-11 demonstrates how the steps of estimating population were operationalized in Arc GIS.

Step 1. Extract raster/pixel values (i.e., population 2015) from population data by wards

Step 2. Extract building footprints used for residential and commercial-residential purposes. The assumption is that the urban population is only concentrated in these buildings

Step 3. Calculate the roof area of each extracted building,

Step 4. Calculate the total roof area of extracted buildings in each ward,

Step 5. Calculate the proportional of the roof area of each extracted building in each ward

Step 6. Calculate the estimated population in each extracted building by multiplying the proportional of the roof area with the estimated population of each ward,

Step 7. Assign the estimated population of each building to each hexagonal grid, and the result is the estimated population for each hexagonal grid.

[6] Population counts 2015 was used so as to have temporal matching with job location data

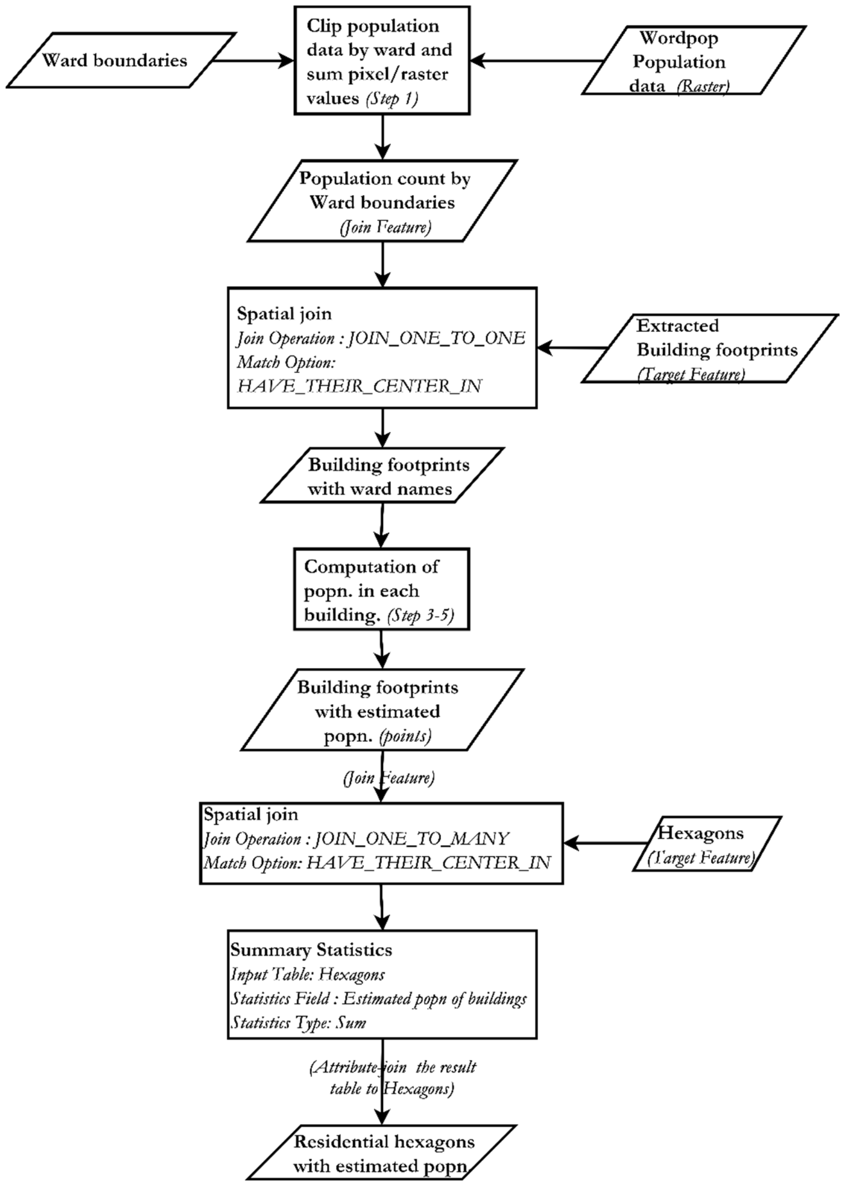


Figure 3-11: Estimation of population in hexagons using Arc-GIS software

Furthermore, the population of each hexagon was categorized/stratified using MPI data by extracting the values from this data into hexagons (Figure 3-12). Different statistical methods are available that can be used to categorize values of socio-economic data such as MPI (J. Martínez, 2005). In this research, a natural break points method was used to categorize the population because it uses a particular break between natural groupings of the data values. The MPI values were classified into four groups and resulted in four socio-economic groups/strata: least deprived, fairly deprived, highly deprived and most deprived. The final hexagons in the study area had an estimated population and socio-economic categorizations based on poverty level. But due to the spatial unit of MPI data to be large (1x1km), the fore mentioned socio-economic groups might have ecological fallacy (i.e., might not represent the real spatial distribution of these groups) in some part of the city specifically in the periphery where there is some mixing of poor and rich people. Figure 3-13 presents the results of socio-economic categorization in hexagons.

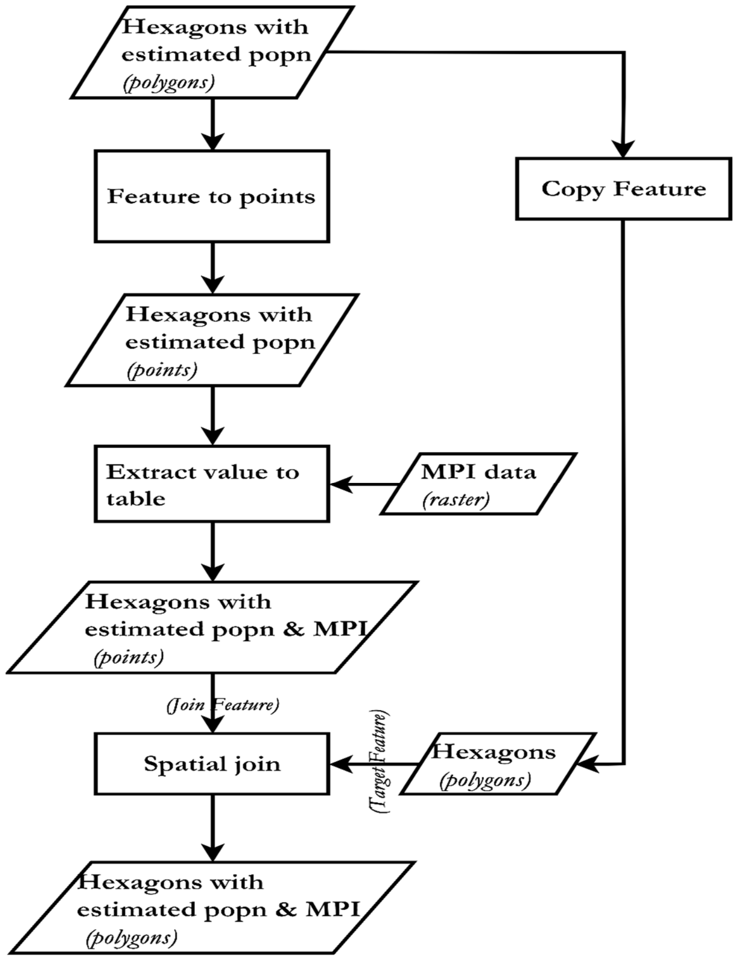


Figure 3-12: Extraction of MPI values to hexagons using Arc-GIS software

Figure 3-14 presents the spatial distribution of socio-economic strata in the study area based on the stratified MPI data as described above. As seen on the figure, the least deprived residential areas (38% out of 42%) are mainly located not far than 10 km from the CBD particularly nearby the trunk roads where most of the economic activities are agglomerated. Only 41% out 42% of most deprived residential areas are located far than 10 km from the CBD where the proposed DART corridors are ending.

3.2.3.3. Job location data

The provided job location data was also structured into hexagonal grids of 250 by 250 meter. This was done in order to make the computation of accessibility to job locations easy. Otherwise, it would calculate over 20 million routes from origins (residential hexagons) to job location points that would take too much time. Each hexagon contains the total number of job centres. Figure 3-13 demonstrates how the job locations were aggregated in hexagons using Arc GIS software, and Figure 3-15 presents the results of job locations in hexagons.

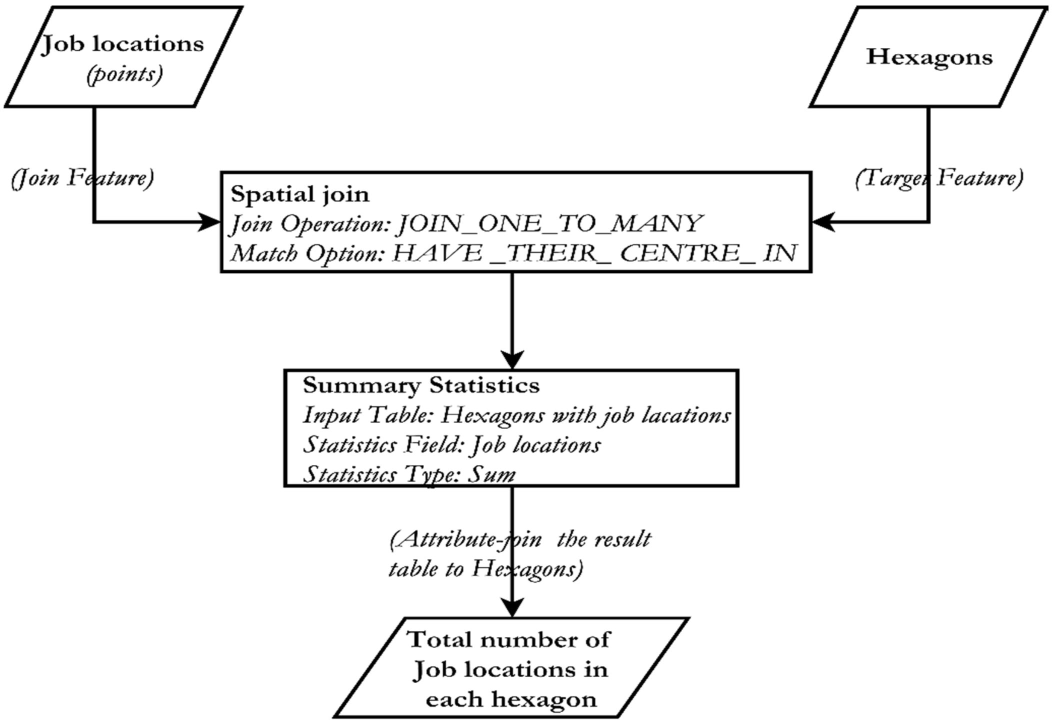


Figure 3-13: Aggregation of job location data into hexagons using Arc-GIS software

Figure 3-15 shows the numbers and spatial distribution of formal job locations (in hexagon units) in the study area. From the figure, it is revealed that the high number of job locations are found within 10km from CBD whereby high agglomeration is along the Pugu and Morogoro roads. This zone of 10km from CBD has diversely of private and public activities. The 5km zone from CBD is highly occupied with commercial and business offices while 5-10km zone is occupied with mixed activities such as light industries, high academic institutions, retail business, etc. Also from the figure, it is evident that most areas out 10 km zone there is a fewer number of formal jobs. This is mainly due to the high development of scattered informal settlements expanding toward suburbs.

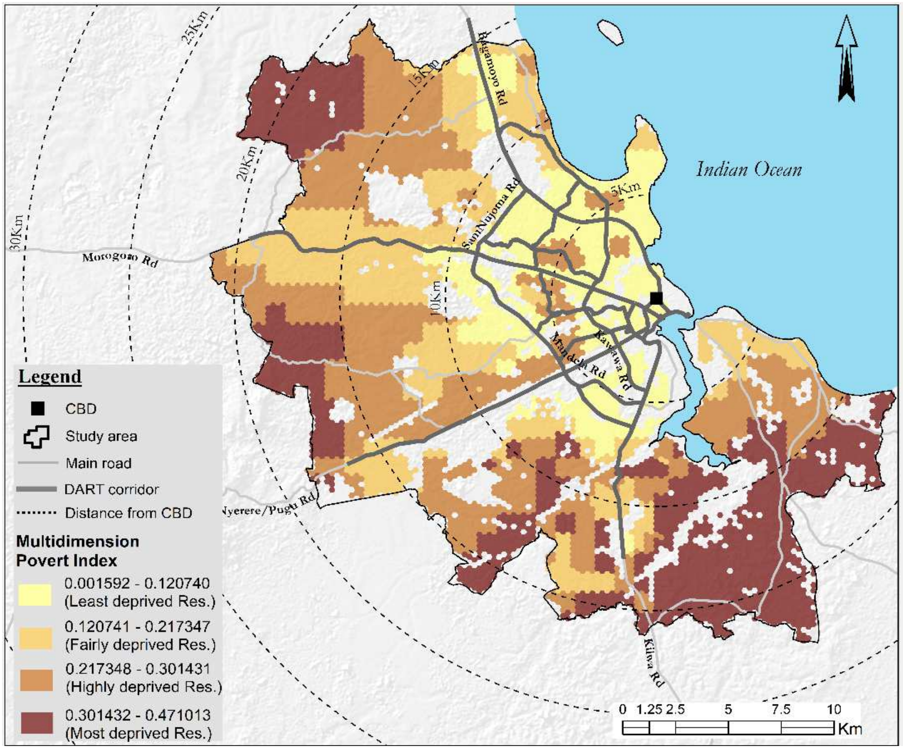


Figure 3-14 Spatial distribution of socio-economic groups stratified by using MPI
Note: White areas within the study area represent areas with no residential areas

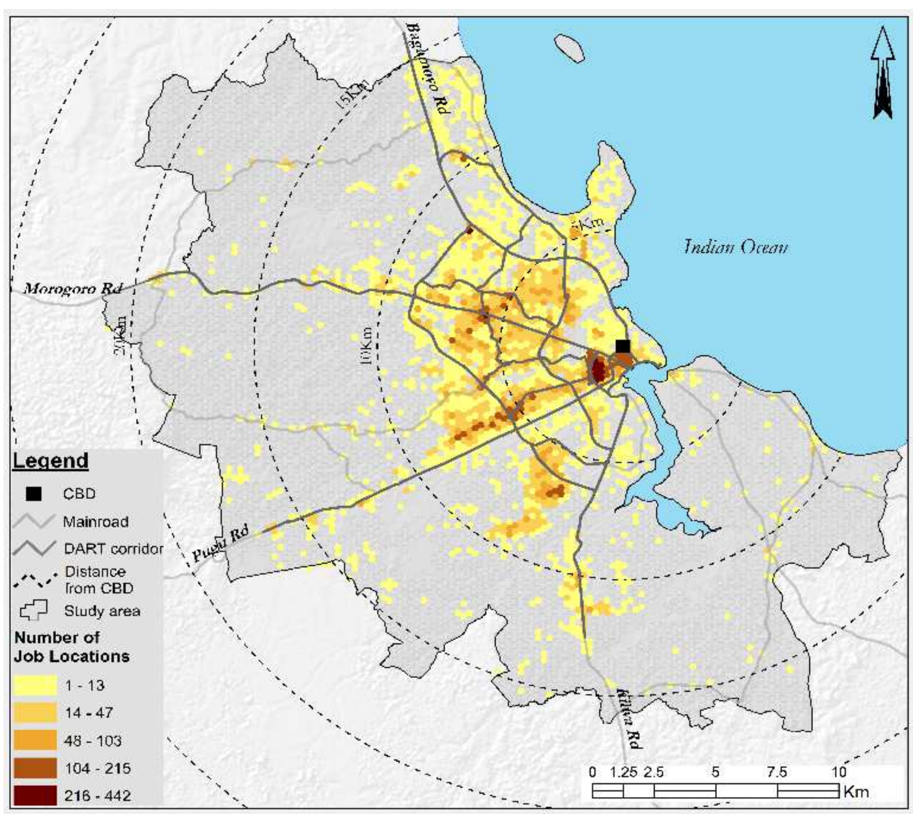


Figure 3-15: Spatial distribution of job locations aggregated in hexagon polygons

3.2.4. DART system modelling in a GIS environment

The proposed DART system was modelled in a GIS environment by considering the commuter trips from residential locations to job locations through the proposed DART system/network. The great attention was given on providing links between service lines/routes of DART system and road network (that used for the walking mode in this research) at bus stops so as to estimate the travel time properly.

Usually commuter trip by public transport is slightly complicated as it occurs between origins (residential locations) and destinations (workplaces) with one or more transport modes. When a trip occurs with more than one mode, it referred to as the multimodal trip, and it involves transfers between modes at bus stops. Figure 3-16 demonstrates the simplified trip along the DART system. The commuter/resident leaves home (origin) to the bus stop by walking[7]. At the bus stop s/he has to wait for the bus, boarding and travel to another bus stop. Then there are three options at the next bus stop either to; continue with the trip in case the bus stops for alighting and boarding of passengers, or descend from the bus and walk to the destination, or take another bus (transfer); waiting for it and traveling in a bus before reaching the final destination.

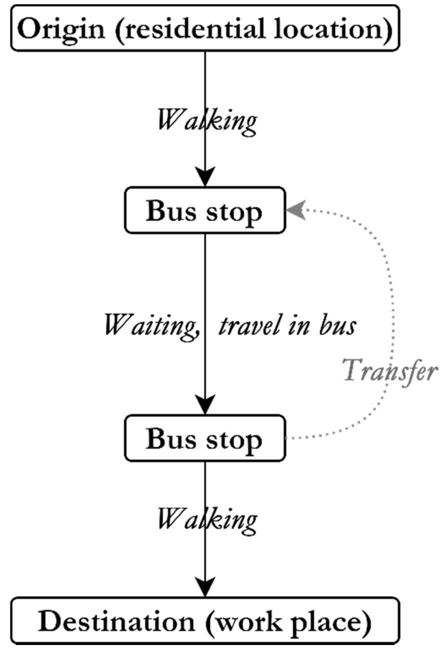


Figure 3-16: Trip along the DART system

Two approaches are available to model the transport network in a GIS environment; modelling by geometry and modeling by attributes. Modeling by geometry is the common approach available in GIS software and has a strong capability for making transport analysis as it allows the use of multiple layers (Miller & Shaw, 2001). In order to model trips of residents as described above via a DART system, the 3D-multimodal network/geometry structure was developed in ArcGIS software (Figure 3-17). Using the connectivity rules in ArcGIS, two levels of connectivity network layers were made. The one level with road network serves as the pedestrian walking from the hexagon centroid of residential locations to the near bus stop or from bus stop to near hexagon centroid of job locations, and the second level with DART service lines to serve as travel between stops. The two levels were linked at bus stops to serve as an entrance/exist between the two travel modes. Two connectivity levels were made specifically to allow separation between walking mode and DART system otherwise all road network/DART service lines junctions would serve as on/off points between DART system and the roads which do not represent the reality.

In order to estimate total travel time between residential and job locations, walking time was assigned in the attribute table of road network (length of a road divides by walking speed), while time in a bus was assigned in the attribute table of DART service lines (length of DART line between two consecutive stops divides by bus speed). But for the case of the waiting time and egress time as travel impedances occur between the connectivity modes (i.e., walking mode and travel mode along DART system), the dummy links[8] were used to assign such impedances. Also, false bus stops[9] were used to provide connections between dummy links

[7] Some cases commuters use other transport modes to reach at the bus stops but this was not applicable in this research because of data unavailability.

[8] Dummy links are hypothetical line segments in GIS-multimodal network environment that provide connection between two different transport modes.

[9] False bus stops are hypothetical bus stops in GIS-multimodal network environment that split bus service lines corresponding to real bus stops.

and DART service lines. The preparation process of both false bus stops and dummy links are shown in Appendix 4.

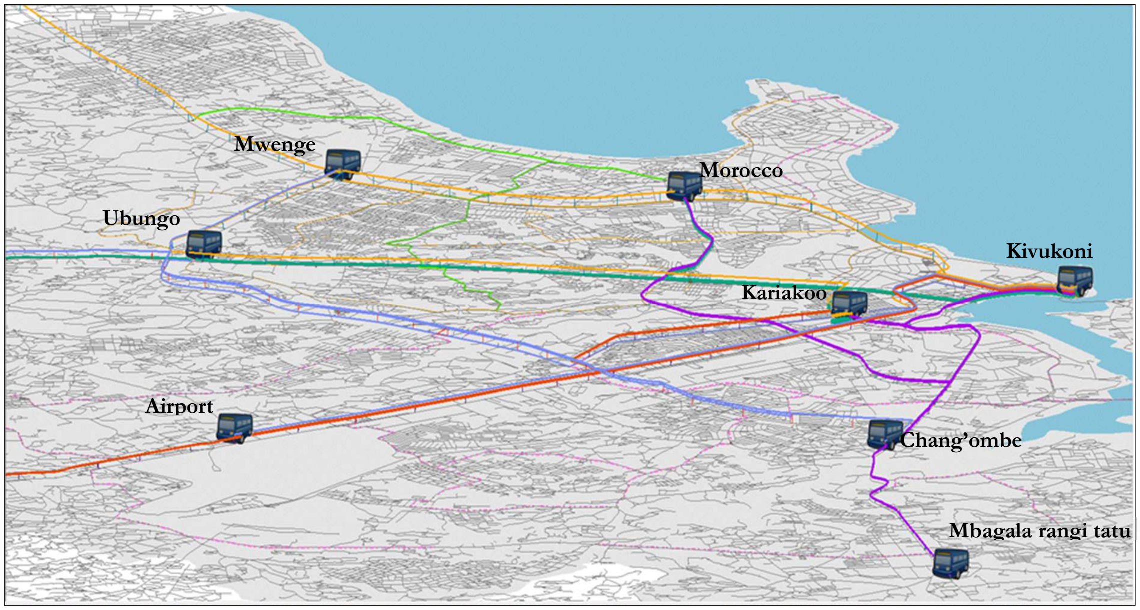


Figure 3-17: A 3D-multimodal network of the DART system

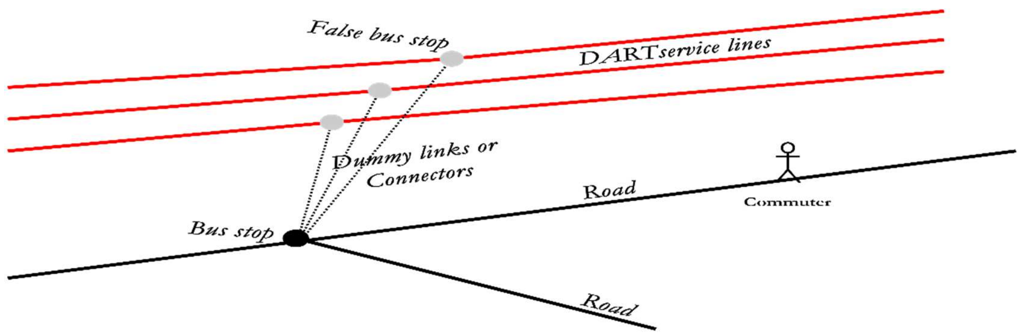


Figure 3-18: Network representation between road and DART networks in a GIS environment

From Figure 3-18, the dummy links provide the connections between roads and the service lines of the DART system. Dummy links have assigned the directions (FT and TF). The directions from the road to the DART service lines were assigned with waiting time (3 minutes) while from service lines to the road is only egress time assigned (1 minute). Both connectivity rule and dummy links were used to represent and assign waiting and egress times commuters incur while boarding to service lines of DART.

Therefore, the developed GIS-multimodal network for the DART system in this research can compute the total travel time between the origin (hexagon centroid of residential locations) and destination (hexagon centroid of job locations). The total travel time was; the walking time to the nearest bus stop plus waiting time, travel time in a bus to another stop close to the job location and finally plus the egress time and the walking time to job location. In case the shortest route between the residential hexagon and job hexagon is just by walking, only walking time was computed and stored in the attribute table during accessibility computation. The estimation of accessibility to job locations was done basing on proposed operational characteristics of DART system at peak hours (i.e., bus speed =23 km/hr, waiting time = 3 minutes and egress time = 1 minute). Finally, the connectivity table between road and DART network datasets in ArcGIS software is shown Appendix 5, and all the attribute variables used to compute accessibility in this research are shown in Appendix 6.

3.2.5. Methods for estimating accessibility and evaluating equity

The applied methods for estimating accessibility and evaluating equity have been divided into four parts as described below.

The **first** part involves the computation of the service area of the proposed DART system so as to determine the population size that is nearby by the DART system. This was computed on the assumption that the BRT system in most cases is considered to have high transit-benefits for those who are close to it (Jiang, Zegras, & Mehndiratta, 2012). The proximity of population to the proposed DART system was calculated around the bus stops/terminals of DART system since the stops/terminal are the actual locations where commuters can access the transport bus service (Foda & Osman, 2010). Using the road network, as a proxy for the existence of sidewalks along it, a walking speed of 4.3 km/h (Rastogi, Thaniarasu, & Chandra, 2011) was considered as the common and monetary-less transport mode for residents to access the public transport service particularly in developing cities (Wu & Hine, 2003). Also walking was selected because many commuters in Dar es Salaam access the bus stops by walking except for those from remote areas where road connection is still poor (DSM City Council, 2018; Chengula, & Kombe, 2017).

A network GIS-based service area was performed to compute service coverage at each proposed DART stop/terminal using pedestrian access time/walking time as an impedance to access the public bus transport service. In this research, the access time of 20 minutes was used as a maximum time for the pedestrian to access the DART stops. This time was selected as the acceptable walking time for an individual to access the public bus service particularly in cities which are not well spatially compacted such as Dar es Salaam (Halden, Jones, & Wixey 2005; Armstrong-wright & Thiriez, 1987). However, there is no consensus in the literature regarding a uniform standard for accessing the BRT stop/bus stop by walking (Jiang et al., 2012). Cervero, Murakami, and Miller, (2010) and Canepa (2007) use maximum catchment area of 400 metres (equivalent 5 minutes walking) up to 900 metres (equivalent 15minutes walking) to assess the access to BRT stops. In this research 5, 10, 15, 20 minutes ware used to check if there are variations to the number of socio-economic groups who can have access to the proposed DART system. Figure 3.19 illustrates the generalized flowchart of the proximity of socio-economic groups by walking to the proposed DART system.

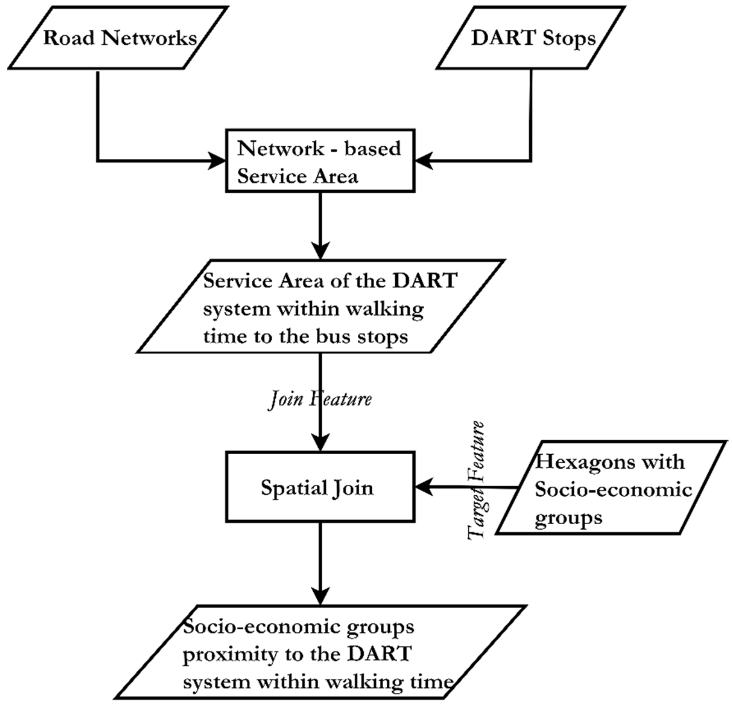


Figure 3-19: Flowchart for the proximity of socio-economic groups to the DART system

The purpose of the DART system as public transport is to serve both origins and destinations, so in the **second** part of the analysis, the accessibility was computed between residential locations that are within acceptable walking time to bus stops and job locations. By using OD Cost Matrix in Arc-GIS[10] based on road networks and the proposed routes of DART system, accessibility of residential locations (as origins) to job locations (as destinations) was estimated using cumulative opportunity measure of accessibility. The advantages and limitations of this measure have been described in subsection 2.1.3. The total travel time was considered as impedances/cost frictions for residents to access the job locations via the DART system. Transit fare also can be considered but in this research, it was not the case because the proposed DART system has planned to use flat fare per trip, so it has no impact on estimating accessibility. The maximum time to access job locations was considered 60 minutes as it is shown by DSM City Council (2018) that the average commuting time for many commuters in Dar es Salaam is not more than an hour. Nevertheless, 30, 45 and 60 minutes travel times were used to see the variation of the number of job locations accessed by each residential groups. Figure 3-20 illustrates the generalized flowchart of accessibility of residential locations to job locations.

In this research, the conventional equation of cumulative accessibility measure (Koenig, 1980) was used to estimate the number of accessible job locations across the socio-economic groups (i.e., mean number of accessible job locations from each residential hexagon) using question 4. Specifically, the calculation of accessibility to job locations via the DART system was considered at morning peak hours when the operation rate is 100%.

$$\mathbf{A_i = \sum O_j \, . \, f(C)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$$\mathbf{f(C_{ij})} = \{ \text{ 1 if } C \leq \text{threshold travel time}$$

---

[10] O-D cost matrix in Arc-GIS was performed to estimate travel cost matrix by creating pairs from each residential hexagon to various job location hexagons. Open trip planner software can also be used to perform the same function if the transport data (such as GTFS,) of particular location are available online.

0 if C >threshold travel time

Where A_i is the accessibility level at residential location **i**, **O** is the number of formal job locations at **j**, **f(C)** is the impedance function from **i** to **j** using public transport mode, **t** is the total travel time between **i** and **j** (i.e. pedestrian access time from i to the bus stop, waiting time, travel time in a bus, transfer time, egress time and walking time to j).

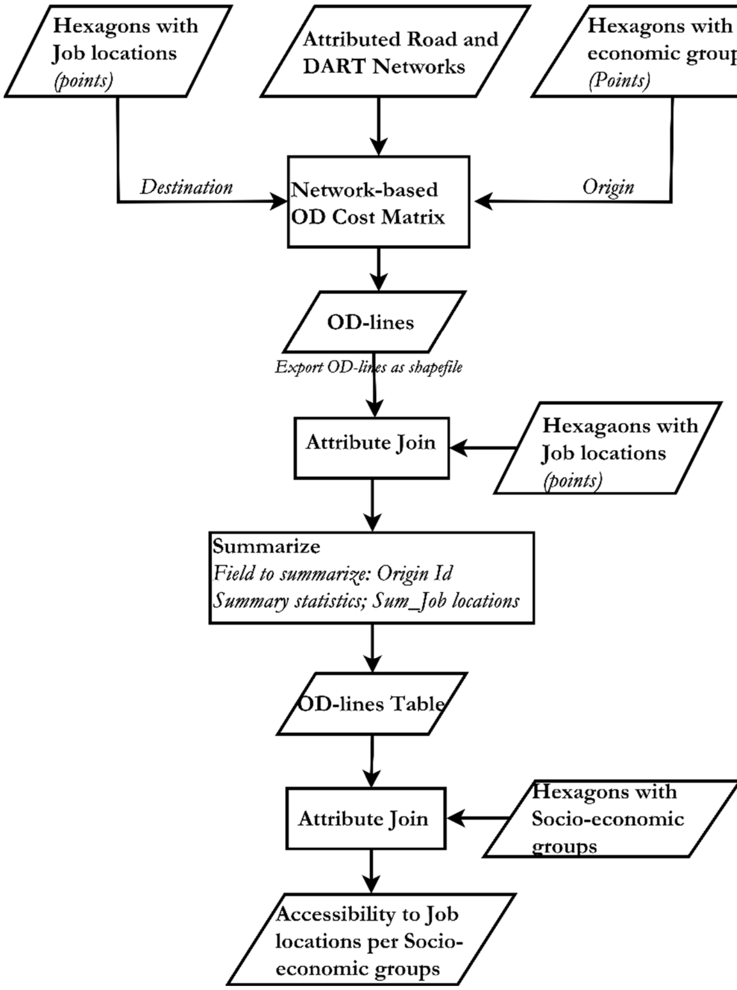


Figure 3-20: Flowchart for accessibility of socio-economic groups to job locations

In the **third** part, statistical analysis using Excel and SPSS software were employed to display tables, graphs as well as to determine the degrees of inequity (using the Gini-indices) for each socio-economic group. The results of accessibility distribution for all socio-economic groups were used as inputs. In this research, the Lorenz curves were constructed using the cumulative percentage of the population (x-axis) ranked by the deprivation levels, and cumulative percentage of accessible job locations at different travel time (y-axis). The degree[11] of equity for each curve was computed as a ratio between; the area under equitable distribution line (45^0 line) and Lorenz curve, and the total area under equitable distribution line (as described in subsection 2.2.2). The Gini coefficients/indices were used to explain the equity levels of job accessibility distribution across different socio-economic groups.

[11] https://www.youtube.com/watch?v=0Vv930-sDTI

In the **fourth** part on exploring the potential residential areas where the proposed DART network could be extended to enhance equity based on accessibility to job locations, assumptions were made based on potential transit demand. In the transport planning field, different approaches are available to estimate the potential demand for transit service in the region. In those approaches data for trip generation, trip distribution, model split, and traffic assignment are considered to understand unmet transit demand. But in this research due to unavailability of such data from the study area, the proximity count approach (De Jong & Van Eck, 1996) was used to explore possible residential areas (unserved ones within acceptable walking time) where the proposed system of DART might be extended to enhance equity based on accessibility to job locations. Assumptions were made by considering residential areas having at least population size of 7000 inhabitants (Metropolitan Council, 2018) and having high transit demand; in this case are highly and most deprived residential areas. These assumptions are in line with the proposed DART development goal for providing transit movement in densely populated areas characterized by deprived society (United Republic of Tanzania, 2007). So to fit such assumptions in computation, OD Cost Matrix was performed between unserved residential hexagons at cut-off time of 20 minutes as an acceptable walking time to the DART stops (Figure 4.2). The OD line results were joined with residential hexagons, and the population was summarized per each hexagon to obtain the cumulative population per hexagon. Residential hexagons that have the cumulative population equal to or more than 7000 particularly in most and high deprived areas were identified as potential areas. Finally, the results were overlayered with trunk and collector roads to identify roads that can be added in the proposed DART system so as to reduce inequities based on accessibility. Figure 3.21 illustrates the generalized flowchart for identifying roads for DART system extension.

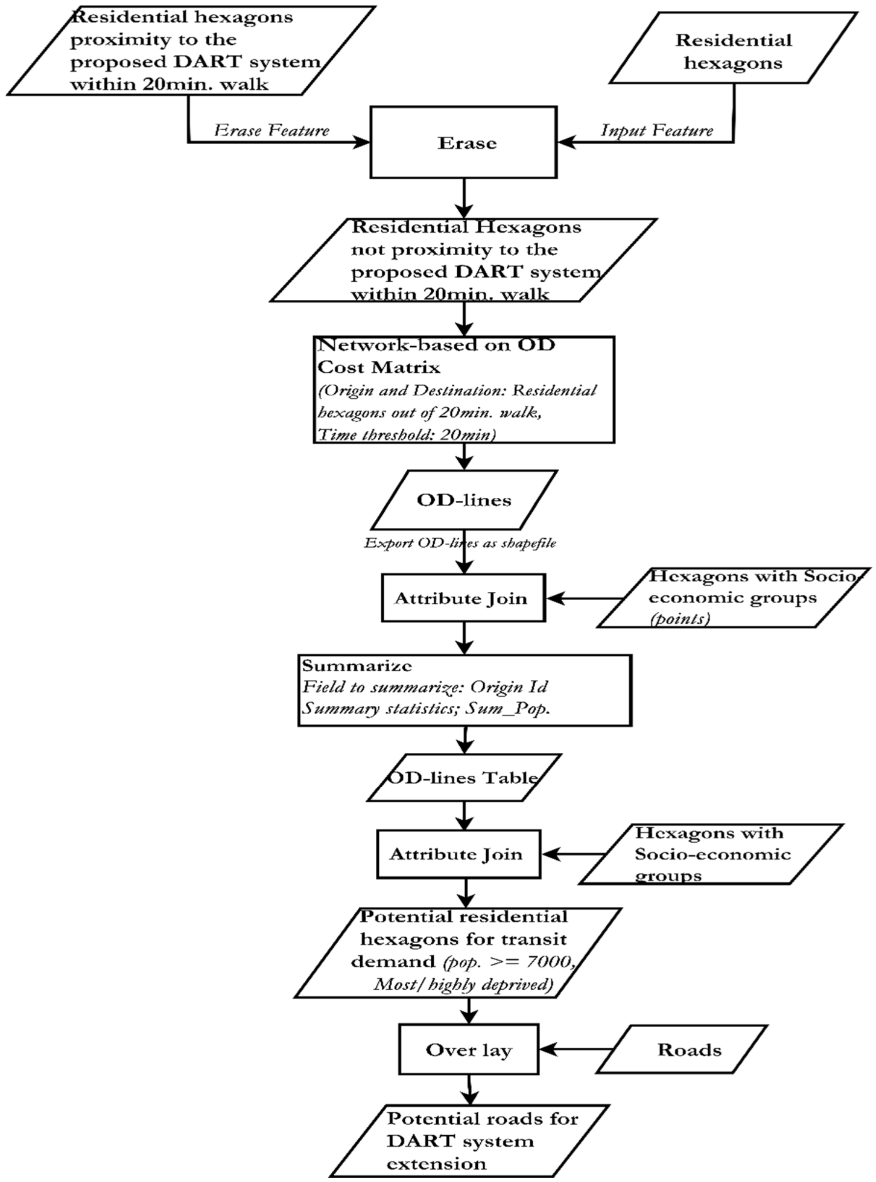


Figure 3-21: The flow chart for identifying roads for DART system extension

4. RESULTS AND DISCUSSION

This chapter presents four main sections; the first three sections provide analysis results based on accessibility estimation, equity evaluation, and potential residential areas for DART system extension respectively. The last section provides a discussion on the results.

4.1. Accessibility estimation

In this section, the service area of the proposed DART system and population served are presented. Also, the section presents the estimation of accessibility to job locations for socio-economic groups who are within 20 minutes walking time to the proposed DART system.

4.1.1. Service area and population served by the proposed DART system

The service area of the proposed DART system was computed in order to measure the ease at which DART service can be reached from different residential locations by walking. Based on network-GIS service area, the area around each DART stop and population within walking time (0-5, 5-10, 10-15, and 15-20 minutes) to the stops were determined. These provide an estimate on a number of people that can access to stops and residential areas that would be served by the proposed DART system. As illustrated in Figure 4-1, a large residential area is covered by 20 minutes' walk to the proposed DART stops especially in areas around 10km from the CBD, and somewhat limited along the major trunk roads for those areas far from the CBD or areas situated in the periphery. In the Southern-East area (Tungi, Vijibweni, Kibada, Mjimwema) almost all residential areas are not served by the proposed DART system, except only a small area close to the Kivukoni terminal. This is because there are no nearest DART stops within 20 minutes' walk apart from a small area of Kigamboni which has a connection to Kivukoni terminal through ferry. Also, Figure 4-1 shows that within 10km from the CBD large residential areas are served not more than 15 minutes' walk to the stops. This is due to the good connectivity of the road and proposed DART networks. In summary, 31% of the residential areas (out of the total residential area in the study area) are within 20 minutes walking distance to the proposed DART system and accommodates around 60% of the total population in the study area (Table 4-1).

Based on proximity by walking to the proposed DART system as demonstrated in Figure 4-2, there is a gradual increase in the service area and population served up to 15 minutes (i.e., equivalent to 1km walking distance). But between 15 - 20 minutes walking time, there is a significant increase in the service area and population served. This implies that most of the served population within 20 minutes' walk is concentrated somewhat far from the DART corridors because of existing other land use development close to main roads. Also, the results from Figure 4-2 indicate that if a minimum walking distance of 400m (about 5 minutes' walk) to BRT stops is considered as proposed by Cervero et al. (2010) and Canepa (2007), only about 5% of the residential area with around 6% of the total population will be served by the proposed DART system. This indicates that within a short walking distance to the DART stops there is a small residential development with few people along the DART corridors.

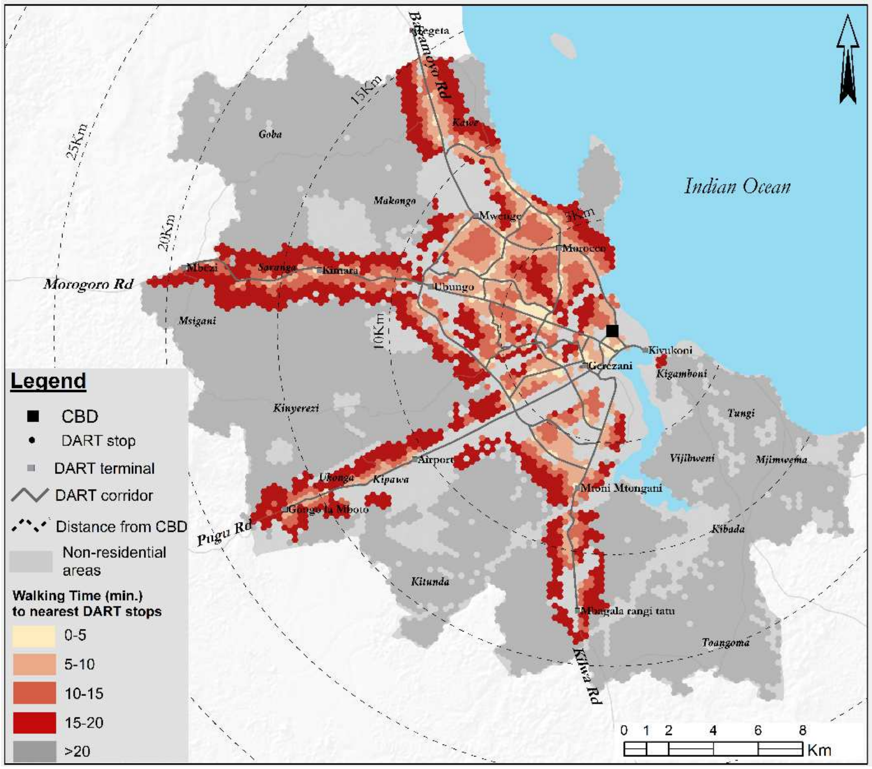
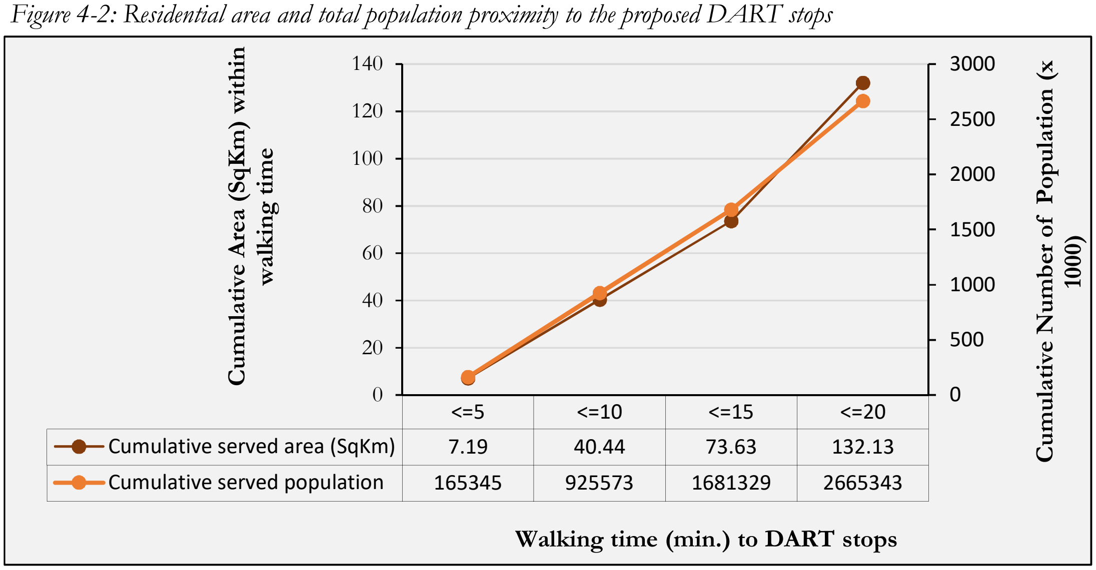


Figure 4-1: Service area of the proposed DART system based on walking time to stops

Table 4-1: Residential areas and population within and out of walking distance to the nearest DART stops

Walking time(min.)	Area (Sq.Km)	Area (%)	Population	% Population
Within 20min.	132.13	31	2,665,343	60
More than 20min.	294.09	69	1,768,629	40
Total	**426.22**	**100**	**4,433,972**	**100**

Figure 4-2: Residential area and total population proximity to the proposed DART stops



Also based on socio-economic groups who are within a 20 minutes' walk to the proposed DART system, Table 4-2 and Figure 4-3 provide quantitative insight on the absolute number and percentage of each socio-economic group that can be served at each 5 minutes time interval. It is shown that at each 5 minutes time interval, the most deprived population has lower access to the proposed DART stops compared to other socio-economic groups except at time interval of 15-20 minutes where 85% of this group can have access. This means that most of the population in this group is not found closer to the DART network. Also from Table 4-2, it is depicted that within 20 minutes' walk, a large number of the least deprived population has access to the DART stops compared to other socio-economic groups. This is because most of the population in this group is found within a 10km distance from the CBD where many of the proposed DART stops are likely to be developed. In terms of the overall population within 20 minutes walking distance to the DART stops, the least deprived population has the highest access to the DART stops followed by the fairly deprived, highly deprived and lastly the most deprived population. For instance, up to 15 minutes walking distance to the DART stops, the least deprived group has 71% of population that can have access to stops, followed by the fairly deprived group with just 67%, highly deprived group with just 42% and least deprived group with just 15%.

Table 4-2: Population by socio-economic groups within walking time to the proposed DART stops

Walking time(min)	**Most deprived**			**Highly deprived**			**Fairly deprived**			**Least deprived**		
	Abs. (000)	%	Cum.%	Abs. (000)	%	Cum. %	Abs. (000)	%	Cum. %	Abs. (000)	%	Cum. %
0 - 5	1.7	3	3	7.3	1	1	25.9	4	4	132.1	9	9
5 - 10	3.3	5	8	78.7	16	17	201.2	30	34	476.4	33	42
10 - 15	5.8	7	15	118.0	25	42	218.8	33	67	413.5	29	71
15 - 20	57.3	85	100	283.7	58	100	218.3	33	100	424.1	29	100
Total	**67.1**	**100**		**487.7**	**100**		**664.2**	**100**		**1446.1**	**100**	

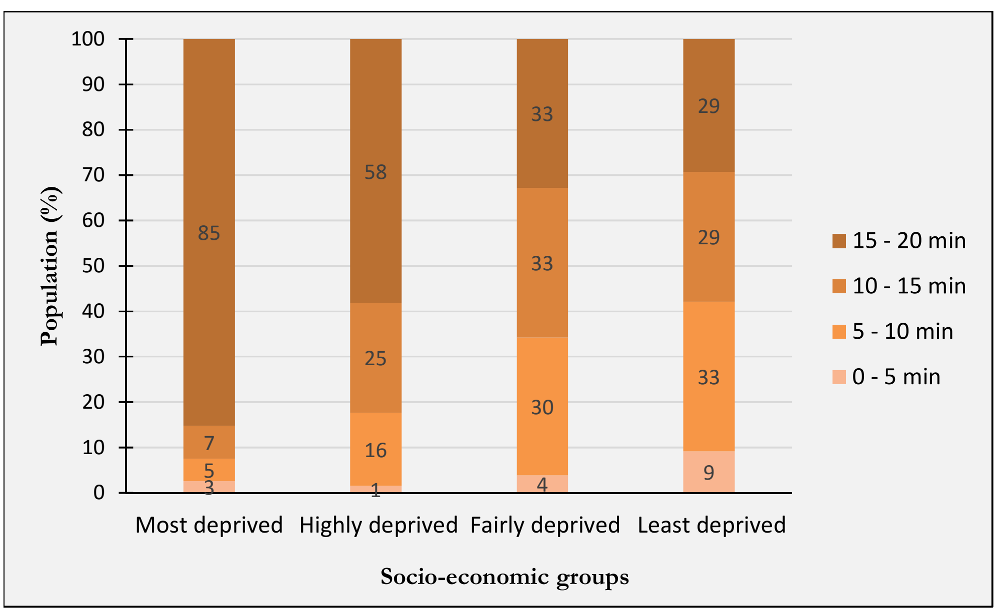


Figure 4-3: Percentage of each residential group per walking time intervals of five minutes to the proposed DART stops

4.1.2. Accessibility to job locations

Since the purpose of the proposed DART system as public transit is to serve both residential and employment locations, accessibility to formal job locations was computed in order to determine the number of job locations that can be accessed by different socio-economic groups who are within 20 minutes walking distance to the proposed DART system. Based on cumulative opportunity measure of accessibility, Figures 4.4a, b, c give a realistic picture of accessibility to formal job locations by presenting a spatial perspective on the number and distribution of reachable job locations from residential locations based on travel times. To allow the comparison between the maps the same scale of accessible job locations was used. Figure 4.4a shows that within a travel time of 30 minutes, residential areas that have relatively high accessibility to potential jobs (13001-20000) are within 5 km from the CBD along Morogoro road. As the travel time increased to 45 minutes (Figure 4.4b) and 60 minutes (Figure 4.4c), the picture of accessibility to jobs changes dramatically as the accessibility distribution spread more out of 5 km from the CBD along the trunk roads. Most of the residential areas along Morogoro, Bagamoyo, and Kilwa roads have more significant gain to job accessibility. This is likely due to more DART service lines from suburb areas to the CBD zone where there is high job agglomeration. Also from all three accessibility maps, it is shown that most residential areas along Pugu road 15 km from the CBD, have relative low accessibility to job locations compared to other residential areas. In practical terms, this is because of long travel time beyond the travel time thresholds, and few DART service lines from those areas to where most job locations are agglomerated.

Additionally, at travel times of 45 and 60 minutes, areas around 10 km from the CDB toward West and North-West have better access to job locations compared to South and South-West. This is because areas toward West and North-West have more DART corridors connection than South and South-West areas. From all three travel times maps also it can be deduced that the South-East areas (Tungi, Mjimwema, and Kibada) have no access to job locations via the DART system because of no DART corridor toward that areas. But a small area at Kigamboni close to Kivukoni has access to jobs because of the connection through ferry which can make people to access the DART terminal of Kivukoni and reach many job locations that are around to the CBD.

Also, Figure 4-5 summarizes the impact of the proposed DART system that could have on the residents' accessibility to job locations under three different travel times (30, 45 and 60 minutes). The results show that for every increase in travel time, there is a significant increase in the number of accessible job locations for each socio-economic group. This means that the proposed DART system will make residents to access different formal job locations that are spatially dispersed within the city. However, for residential locations that are somewhat distant from job locations would have smaller benefit from the DART system because of travelling a long distance in a bus to access the job locations. Also, the results show that at all three travel times the least deprived population can access many numbers of job locations compared to other deprived groups. Whilst the most deprived population can access few numbers of job locations compared to other deprived groups.

a.

b.

c.

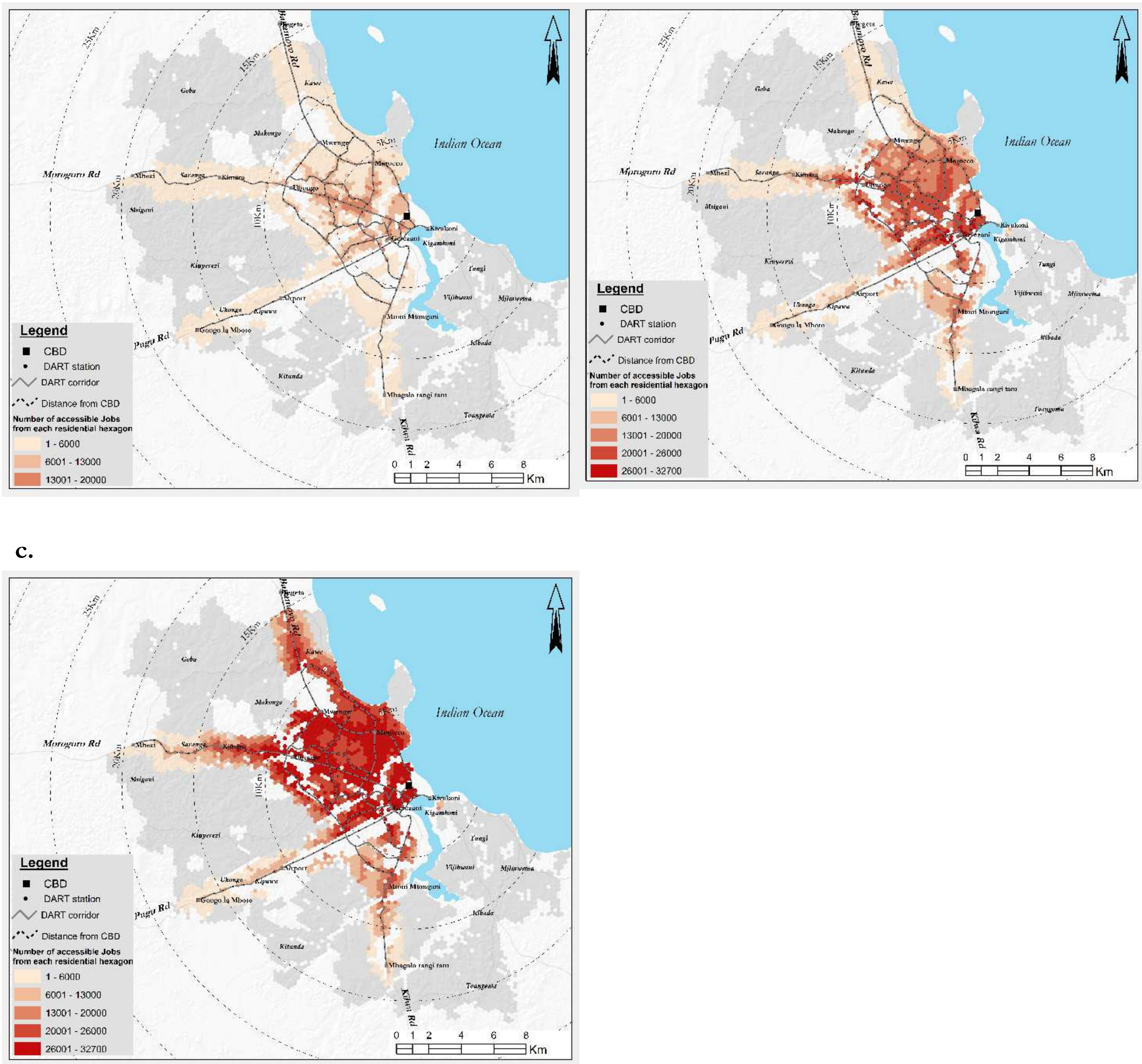


Figure 4-4: Number of accessible jobs within 30min, 45min, and 60min by the proposed DART network

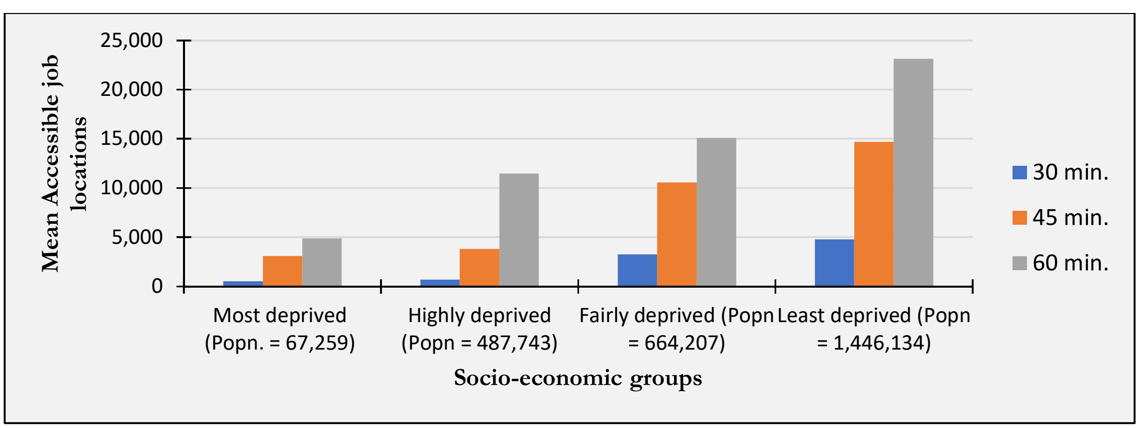
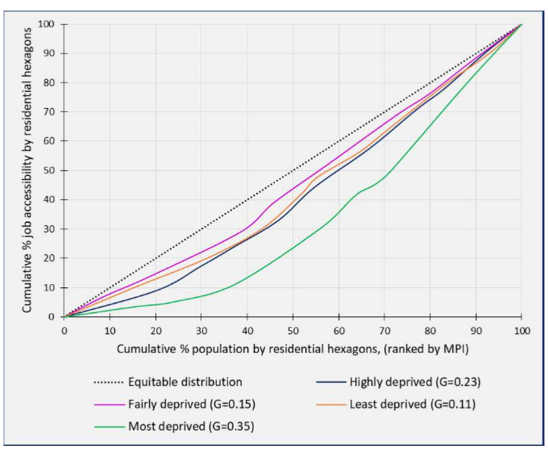


Figure 4-5: Mean number of accessible jobs per socio-economic group within 30min, 45min, and 60min. by DART network

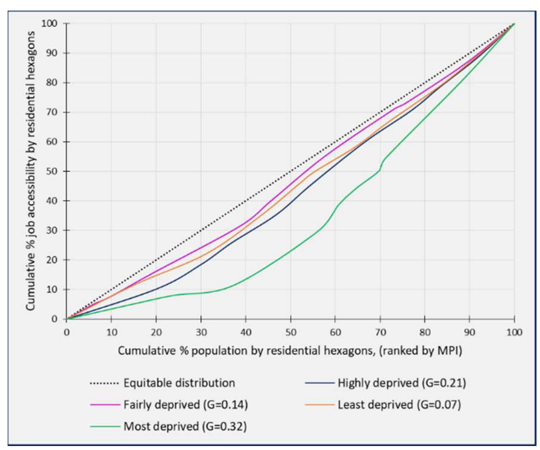
4.2. Equity evaluation based on accessibility to job locations

Since vertical equity in transport planning strongly relates to distribution of transport effects such as accessibility to opportunities particularly for those who are worse of (Wee & Geurs, 2011), this section presents an analysis to determine the degrees of inequity based on accessibility to job locations across the socio-economic groups. In another way round, this analysis determines the degree of variations of job accessibility distribution across the population of socio-economic groups. Gini indices in Lorenz curves were used as they provide moral and normative dimensions that allow equity analysis beyond the arithmetical imbalances (as presented in subsection 4.1.2) of job accessibility distributions among the socio-economic groups. (DeVerteuil, 2009).

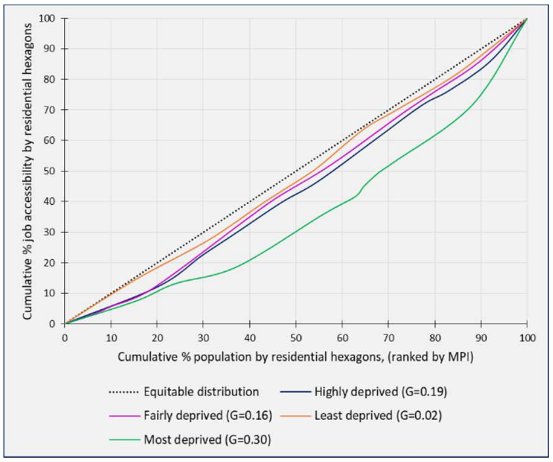
Figure 4-6a,b,c present the Lorenz curves along with their corresponding Gini indices that indicate the distances of job accessibility situation from the perfect equity at three travel times used in accessibility analysis. The curves mark-out the cumulative percentage of job accessibility (y-axis) against the cumulative percentage of the population (x-axis). The results show that at all three travel times the most and highly deprived population have relatively high degrees of inequity (as presented by Gini indices) compared with least and fairly deprived population. This reflects that at all the three travel times the job accessibility is not evenly spatially distributed across the most and highly deprived population who are tend to be more transit dependents on accessing job opportunities. For instance at one hour travel time, Figure 4-6c depict that 50 percentage of the most deprived population can experience about 30 percentage of accessible job locations which is less compared with other socio-economic groups, who experience more than 40 percentage. The similar trend can also be deduced even in shorter travel times (30 and 45 minutes) as can be seen in Figure 4-6a and b respectively. The results also show that at all three travel times the least deprived population have relatively low degrees of inequity (as presented by Gini indices) compared with other deprived population.



a. Travel time =30 min.



b. Travel time =45 min.



c. Travel time =60 min.

Figure 4-6: Lorenz curves and Gini indices for each socio-economic group at different travel times (60 minutes time threshold was used as an average travel time people in Dar es Salaam like to spend in accessing their workplaces)

4.3. Potential residential areas for DART system extension

The results in section 4.2 indicate that there is some degree of inequity based on job location accessibility for the population living within 20 minutes walking distance to the proposed DART network. In this regard, this section aims to explore the potential residential areas where the proposed DART network could be extended in the future so as to reduce inequitable job accessibility distribution across the socio-economic groups.

4.3.1. Unserved residential areas

As indicated in Figure 4-1, a large part of unserved residential areas by the proposed DART system is located more than 10 km away from the CBD, except for the South-East area where there is no DART corridor. The total population in these areas is about 40% of the total population in the study area. Figure 4-7 also illustrates the population size by socio-economic groups that are not within walking distance to the proposed DART system. It is depicted that a large percentage of most and high deprived population are not living close to the DART system by walking. This means that they are required either to walk more than acceptable distance or use other modes of transport to access the proposed DART stops before accessing the job locations.

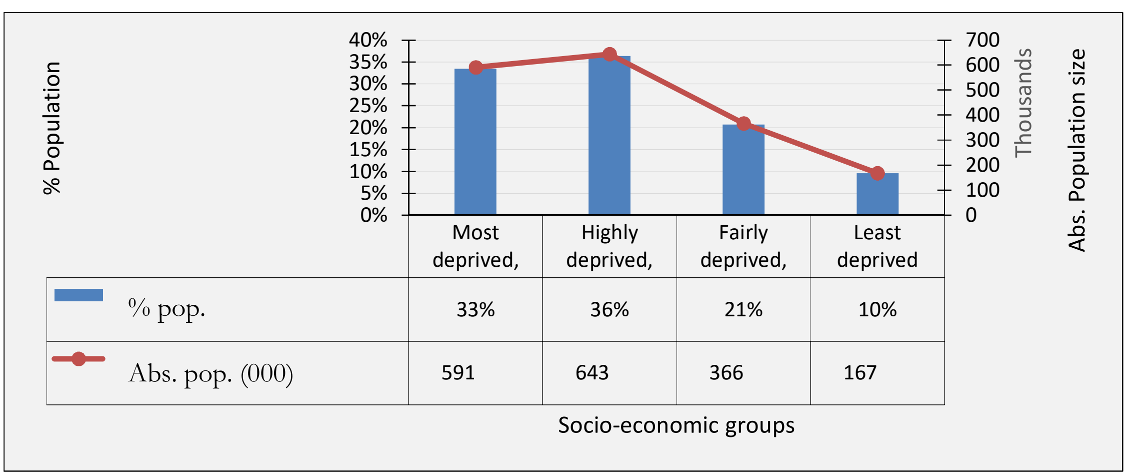


Figure 4-7: Population size (in percentage and absolute number) by socio-economic groups not served by the proposed DART system

4.3.2. Residential areas for DART system extension

In subsection 4.3.1 the population size by socio-economic groups that are not in proximity by walking to the proposed DART system was identified. But a crucial issue of social justice point of view is to ensure that the proposed public transit such as DART system able to reduce inequity through offering fair access to opportunities, particularly to the most and highly deprived residential locations. The next step in this section is to identify where the most and highly deprived population reside so that the proposed DART system can be extended in the future and hence reducing inequity based on accessibility to job locations. However, the proposed DART system cannot be extended where there is no or low demand. So to meet such criteria, the potential residential areas having the population size of 7000 inhabitants or more, and located within walking distance of 20 minutes were first identified using proximity count accessibility measure as described in subsection 3.2.5. The results then were overlaid with socio-economic groups to identify where the most and highly deprived population can ensure ridership to the extended DART system.

Figure 4-8 shows unserved residential areas by the DART network having potential population size to meet the demand for DART network extension. The result indicates that most potential areas have 7000 to 50000 population size and few areas with greater than 50000 population. Also, figure 4-9 shows residential areas with the highest potential demand where the proposed DART system can be extended to reduce inequity based on proximity by walking to the DART system and accessibility to job locations. The result indicates that residential areas located in between the proposed DART corridors 10km away from the CBD, and residential areas located in South-East are the potential for the DART system extension since they have the population with most and highly deprived people. These residential areas are the unserved areas (from the proposed DART system) with the potential population of extending BRT system serving more than 7000 population.

Also from the existing road networks of Dar es Salaam, main roads that are close to the residential locations having potential demand (in this case close to most and high deprived areas) were identified and shown in Figure 4-10. This was adopted since it has a more economical option than opening a new corridor for the proposed DART extension. The identified roads can enhance equity based on accessibility to job locations since the high speed of the proposed DART system could able to connect these deprived areas to the agglomerate job areas within a short travel time.

Furthermore, to make these extended DART corridors to have a more beneficial impact on enhancing equity based on accessibility to job locations, the decentralization of the formal jobs/activities[12] can also be considered instead concentrating formal jobs only at the CBD zone. This can at least make the population in most and highly deprived areas to spend not much time on accessing many potential jobs via DART network.

[12] The scenario for decentralizing of the formal jobs/activities closer to the extended DART corridors was not performed in this research because of its modeling complication in GIS software.

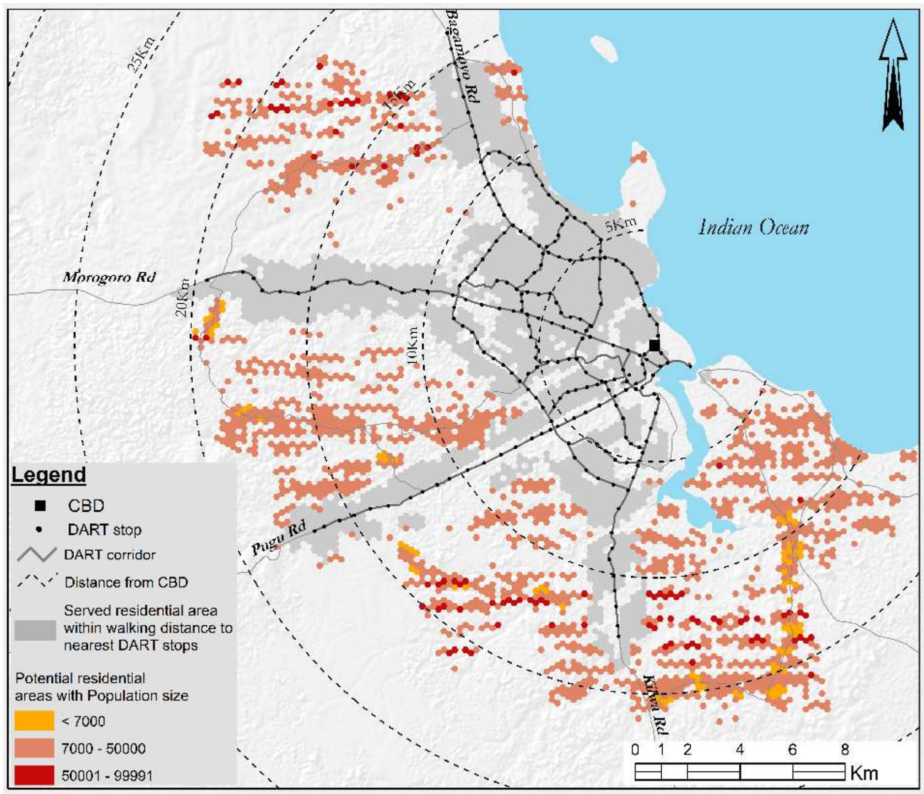


Figure 4-8: Potential residential areas (with population size) for the proposed DART system extension

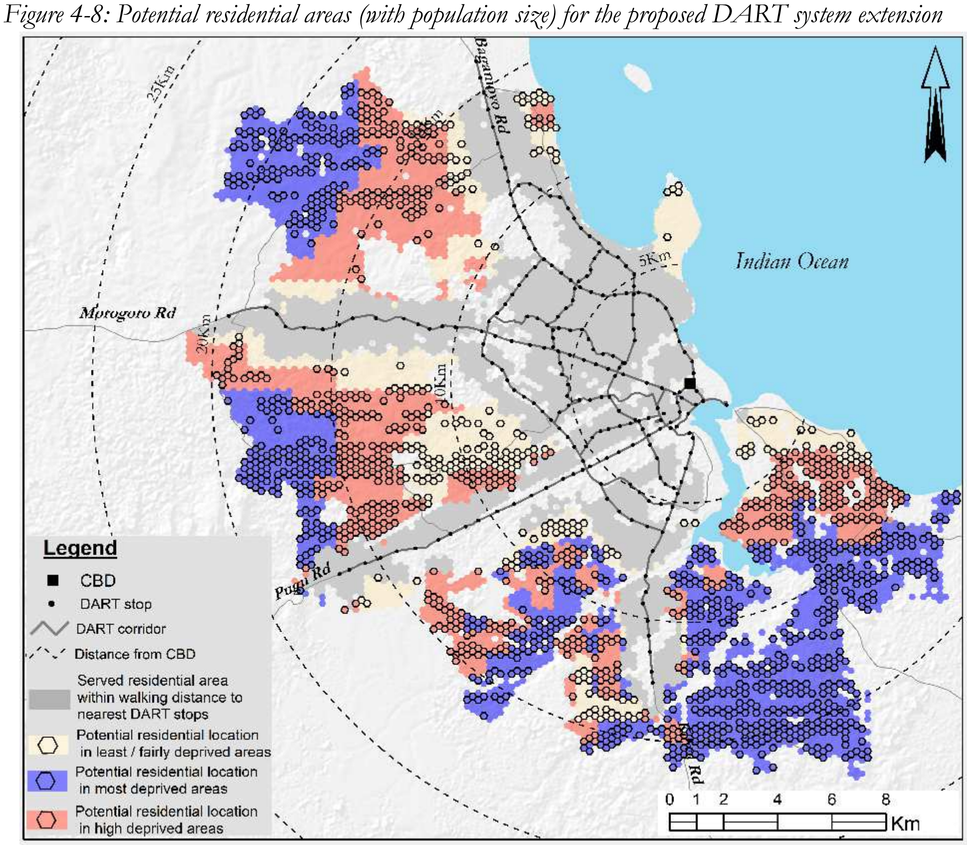


Figure 4-9: Potential residential areas for the proposed DART system extension

Note: Black circles represent population size greater than or equal to 7000 overlaid with socio-economic groups

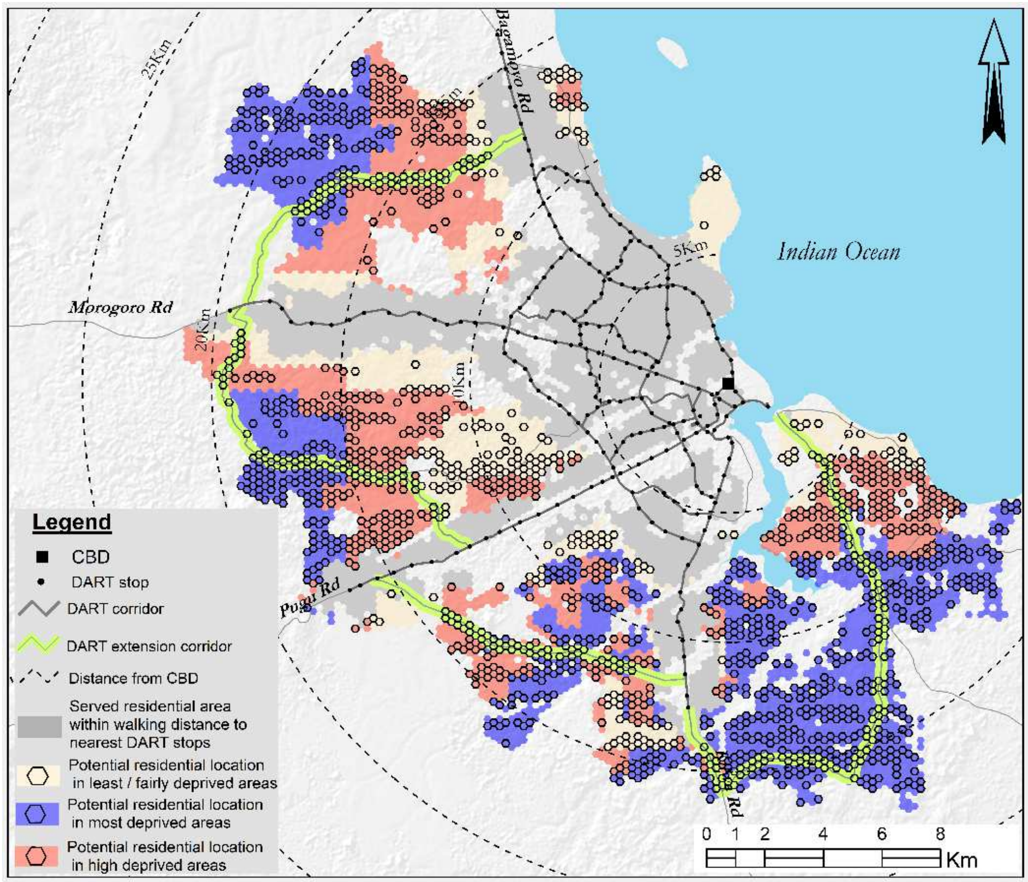


Figure 4-10: Identified roads for the proposed DART system extension

4.4. Discussion on the results

4.4.1. Service areas and population served by the proposed DART system

This study attempts to evaluate the equity of the proposed BRT system in Dar es Salaam (under full implementation by 2035) based on accessibility to job locations for the population living within a desirable walking distance of 20 minutes to that BRT system. Findings of this study indicate that within a zone of 20 km from the CBD (see Figure 4-1), the residential areas served by the proposed DART network is 31%, that is about 12% of the all residential areas in Dar es Salaam. Also, 60% of the population of the case area have access to DART stops, representing about 49% of the entire population of Dar es Salaam. Within the desirable 20 minutes walking distance, access to the proposed DART stops across the socio-economic groups is not uniformly distributed. However, the least deprived population group in the city have a certain favourable access to the DART system because they are within the densely developed DART network zone as compared with the other population groups such as the most, high and fairly deprived population. This is in line with the study conducted by Scholl and Gray (2016) in Lima-Peru and Boisjoly, Serra, Oliveira, and El-geneidy (2019) in four cities of Brazil where they discovered that higher proportion of high-income households have high access compared to low-income households located closer to the rapid transit. According to Marks, Mason, and Oliveira (2016), this is because in many cities rapid transit corridors such as BRT system appear to be developed in areas of relative affluence and not extend far to the periphery where the majority of poor resides. Also, the findings of this study in another way round disagree with the findings in Cali-Colombia by Scholl and Gray (2016) and Bogota-Colombia by Teunissen, Sarmiento, Zuidgeest, and Brussel (2015) which discovered that lower socio-economic classes benefit a high level of access by walking to a BRT system. The difference in results from this study is because of the differences in planning development control policies whereby in some Global South cities have policies of locating low income people near the mass transit. For example, Bogota has policies such as social housing development which tend to favour low-income population to be located closer to the public transit corridors (Silva, 2016).

4.4.2. Accessibility to job locations

An analysis of accessibility to job locations has the potential of promoting opportunities for interaction between the BRT system and land use (Brussel, Zuidgeest, Pfeffer, & van Maarseveen, 2019). Findings on the full implementation of the DART system as new rapid transit policy show that there is a high potential of promoting of transport-land use integration, which can connect people nearly to most formal job locations within the city. However, the operationalization of the DART system implies that the least and fairly deprived population stand the chance to benefit most than most and highly deprived population groups. This phenomenon appears because the least and fairly deprived population are located near the inner city, where there is high formal activity concentration with well BRT service lines providing good accessibility. This finding is consistent with the studies by Hernandez (2018); Pereira (2018) and Boisjoly et al. (2019) who found that the lowest socio-economic households are largely disadvantaged in terms of accessibility to jobs via rapid public transits in Latin American cities such as São Paulo, Rio de Janeiro, Curitiba Recife and Montevideo due to poor connectivity of public transport to workplaces within a short travel times.

4.4.3. Equity evaluation based on accessibility to job locations

The Lorenz curves and Gini indices across each socio-economic group at different travel times assess the proportional of the population that experience low and high job accessibility distribution. The findings in this study show a relative inequitable access to job locations via the proposed BRT system in Dar es Salaam, as greater proportional of the most deprived population at all three travel times experience lower proportion of accessibility to job locations as compared to other deprived population. These findings are similar to the findings of Boisjoly et al. (2019) in Brazilian cities whereby statistically discovered that at 60 minutes travel time, low-income households have lower job accessibility compared to the high-income households. The results obtained in this study proves that in some Global South cites, to some extent, the benefits of the BRT system based on accessibility to opportunities are skewed towards affluent people due to its insufficient spatial coverage to connect poor people to important opportunities or services as claimed by (Venter et al., 2017).

4.4.4. Potential residential areas for DART system extension

Regarding the results of DART network extension to enhance equitable accessibility to job locations indicate that more extension is required to the periphery of the city where the most and highly deprived population are located. This would likely to have a significant impact on job accessibility to these socio-economic groups as it can able to connect them to formal jobs that are most found to the CBD. But, as it indicated in the analysis in subsection 4.1.2 being only in proximity by walking to the DART network for these socio-economic groups is not sufficient to ensure high accessibility levels to job locations because most of the formal jobs located closer to the CBD. According to Martínez, Hodgson, Mullen, and Timms (2018) and Delmelle and Casas (2012) in their studies, it is also crucial to consider the issue of formal activity decentralization by developing job centres and services closer to where the low income population reside in order to reduce the accessibility gap between the low income and high-income population. So in this regard, developing job centres closer to the extended DART corridors could also be essential in order to support more equitable distribution of accessibility to jobs across the socio-economic groups. This can only be achieved through developing and implementing land-use policies that focus on a better distribution of jobs and hence reducing the monocentric structure of the city in term of employment. Furthermore, as demonstrated by Boisjoly et al. (2019) formal activity decentralization can also support informal sector development in which many low-income population depends on, particularly in Global South cities.

5. CONCLUSION AND RECOMMENDATION

This study has examined the equity evaluation of the proposed BRT system in Dar es Salaam (DART) based on accessibility, and explore the potential areas where DART network could be extended to enhance equity within the city. Using the quantitative methods with a combination of both spatial and non-spatial data, this study analyzed the service area and population served within 20 minutes walking distance to the DART stops, accessibility to formal job locations, equity evaluation based on access to formal job locations, and potential areas for the DART system extension to enhance equity. The findings indicate that within the study area about one-third of the total residential area can be served and accommodates a large number of population within 20 minutes walking distance to the DART stops. Evaluating this access by socio-economic groups, the findings revealed that a greater number of least and fairly deprived population can have good walking access to the DART stops compared to the most and highly deprived population. The reason behind that is due to good spatial coverage of the DART network where the least and fairly deprived population reside and much limited of the network to the periphery where a large number of most and highly deprived population live.

Based on accessibility to formal job locations, the proposed DART system can connect a large number of city's population to the widely dispersed jobs within the city. But high accessibility level can be experienced by the least and fairly deprived population. This is because the least and fairly deprived population are located nearby the job concentration areas where there is a good connection of DART service lines compared to the most and highly deprived people, who are in the periphery where there is little DART service lines connection. Additionally, the equity evaluation across the socio-economic groups shows inequitable access to job locations via the DART system. The most deprived population have a relative high degree of inequity than other deprived groups at all travel times to job locations. This suggests that if there is no intervention taken place, the proposed BRT system in Dar es Salaam may favour more of the socio-economic well off areas than worst-off areas particularly located at the city's periphery.

Finally, based on accessibility measure this study concludes that in order to reduce an inequitable job accessibility distribution, more extension of DART corridors is required to the city's periphery. This can increase both the DART's system service area and its connection to a large number of most deprived population to job locations. Also, the extended DART corridors can be more useful if they are developed together with formal and informal activities nearby. This can lead to the reduction of the job accessibility gap between the most and least deprived population.

In summary, basing on study findings the lesson that can be drawn is that if attention could not be taken by policy makers and transport planners incorporating accessibility analysis in BRT investments, there is a possibility of these investments to invigorate cities' economic development but not overcoming the legacy of inequity across the socio-economic groups.

Limitations and Recommendations for future research

The present study has examined the equity evaluation of the proposed BRT system in Dar es Salaam using physical accessibility. The analysis methods applied in this study can also be replicated with some adaptations in another local context to understand the significant benefits of the BRT system in term of transport-land use interaction to different socio-economic groups and hence the equity impact of the BRT system. But the limitations of using physical accessibility in this study need attentive attention in future studies.

First, the analysis of the service area of the DART system and population that can be served does not consider those who can have access using other transport modes apart from 20 minutes walking. This can be an issue that may be important for users using multiple connections before accessing the BRT stops

Second, due to data unavailability the job accessibility analysis does not consider the informal jobs within a city, the issue that is very important in Global South cities with an underground economy (Pereira, 2018). In Global South cities such as Dar es Salaam large relative share of their population depend on economy constituted with informal labour market (Blades, Ferreira, & Lugo, 2011).

Third, the analysis of access to job locations does not consider distance decay and competition factors. Instead, all the formal job locations treated equally in access. In real life, this is not the case since some job opportunities cannot be accessed by particular individuals due to their individual components such as education level. Therefore the analysis of this does not reflect the travel behavior of individuals to provide a clear picture which job locations have higher access than others.

Fourth, the analysis of this study used the Multidimensional-poverty-index (MPI) data to disaggregate the population in terms of socio-economic perspective. But due to its low resolution of 1x1km, this might led over/underestimation of accessibility by socio-economic groups in some part of the study areas where there is a mixing of different income people. Another study can use data which is not much aggregated (e.g., income by household levels) to categorize population for evaluating the equity in transport accessibility.

Finally, the analysis focused only on accessibility (not in other dimensions of equity) to understand the progressive benefits of the BRT system across the population segments. The future study can examine the BRT system in another dimension of equity such as affordability (appropriateness of its fare structure toward the socio-economic groups) and health and safety (exposure of pollutants and health effects to its user and non-users).

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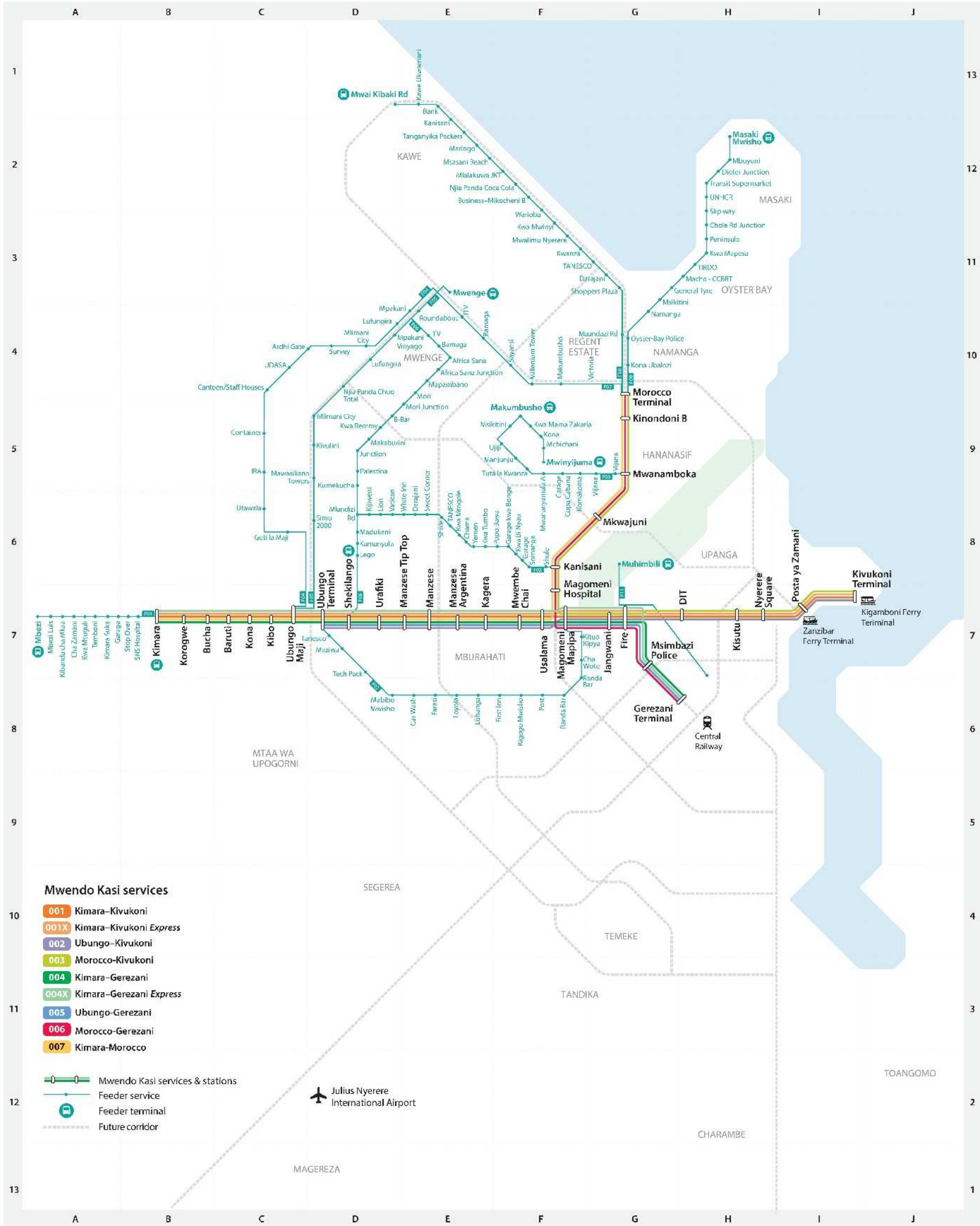
APPENDICES

Appendix 1: BRT phase-1 on segregated lanes while commuter buses/daladala on mixed lanes

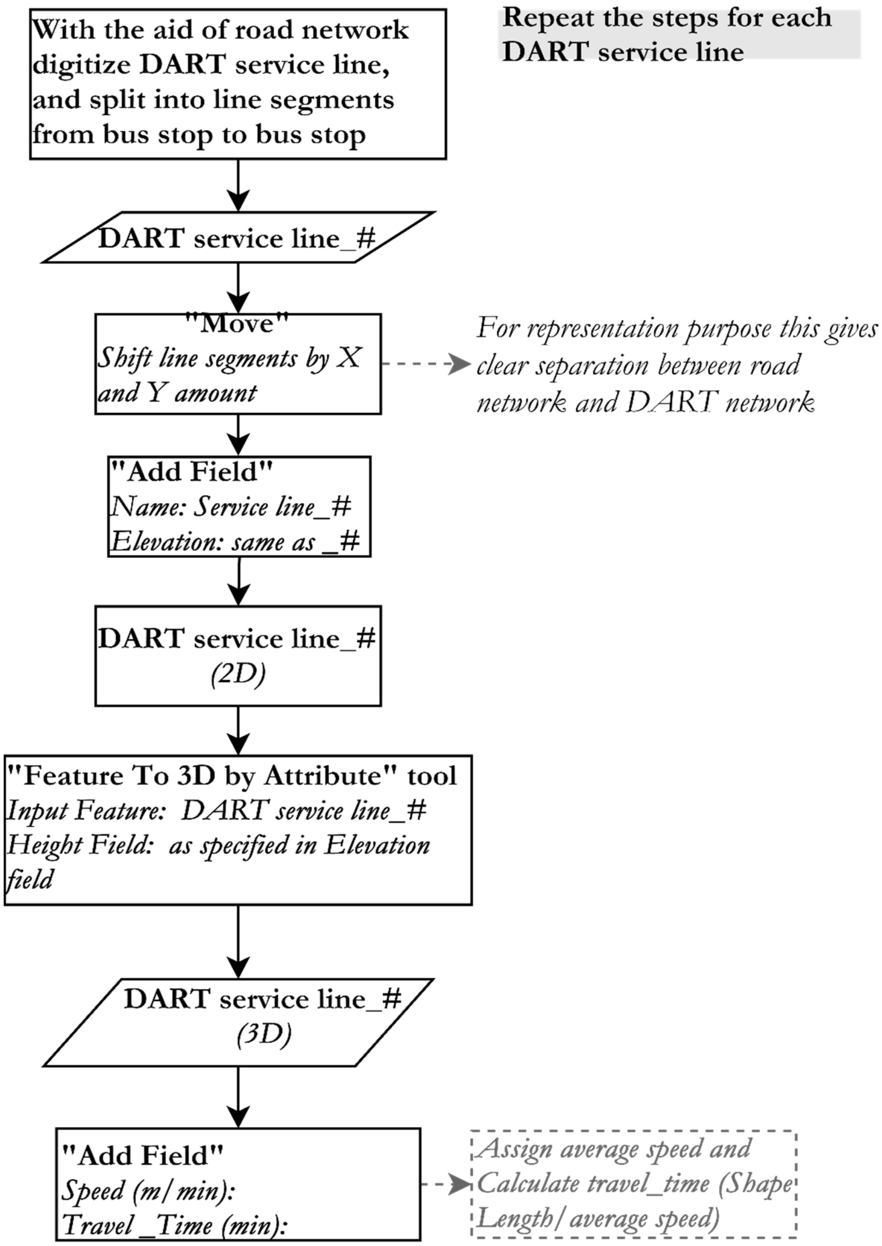
Appendix 2: BRT phase-1, trunk, and its feeder routes



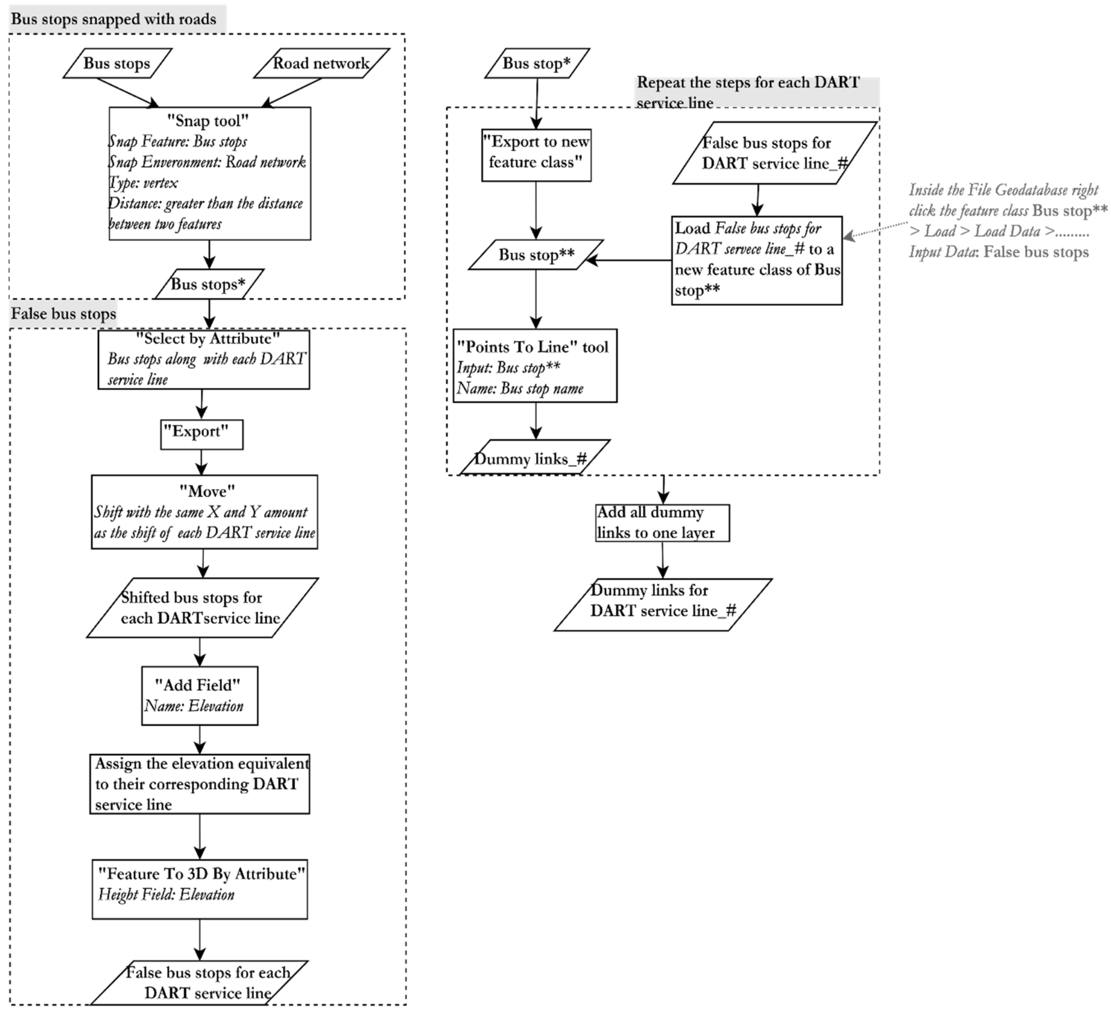
Mtandao wa Mwendo Kasi

DART
DAR RAPID TRANSIT

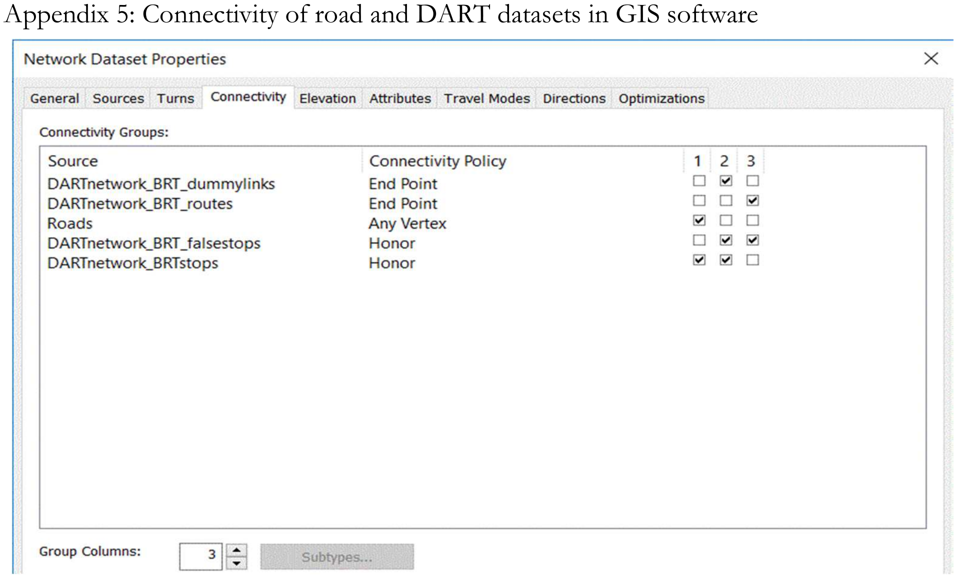
Appendix 3: Preparation process of DART routes/ service lines



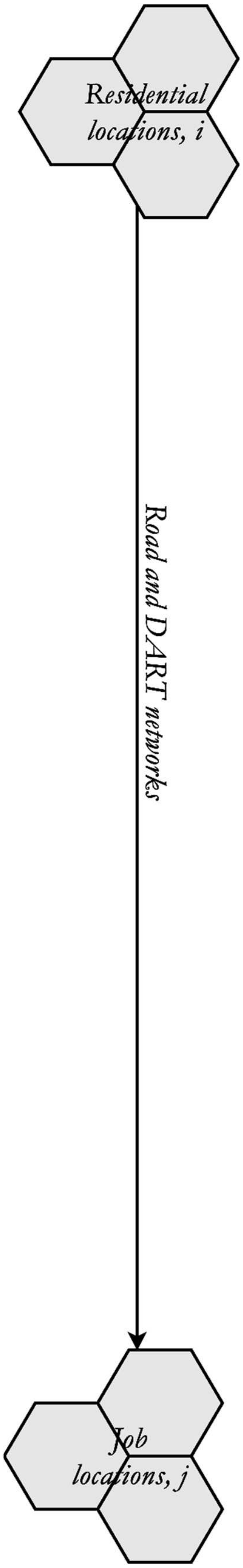
Appendix 4: Preparation process of False bus stops and Dummy links/connectors



Appendix 5: Connectivity of road and DART datasets in GIS software



Appendix 6: Attribute variables used to compute accessibility in GIS-environment



Table

Residential_Hexagons

FID	Shape *	OBJECTID	Region_Name	District_Name	Ward_Name	MPI.value	Socio_economic_groups	Pop_2015_Worldpop
5464	Polygon	5465	Dar-es-salaam	Ubungo	Saranga	0.279972	Highly deprived	379
5507	Polygon	5508	Dar-es-salaam	Ubungo	Saranga	0.284344	Highly deprived	40
5509	Polygon	5510	Dar-es-salaam	Ubungo	Saranga	0.279972	Highly deprived	135
5510	Polygon	5511	Dar-es-salaam	Ubungo	Saranga	0.279972	Highly deprived	378
5511	Polygon	5512	Dar-es-salaam	Ubungo	Saranga	0.279972	Highly deprived	309
5558	Polygon	5559	Dar-es-salaam	Ubungo	Saranga	0.279972	Highly deprived	281
2604	Polygon	2605	Dar-es-salaam	Ilala	Segerea	0.150841	Fairly deprived	194
2605	Polygon	2606	Dar-es-salaam	Ilala	Segerea	0.23972	Highly deprived	89
2606	Polygon	2607	Dar-es-salaam	Ilala	Segerea	0.270391	Highly deprived	252
2689	Polygon	2690	Dar-es-salaam	Ilala	Segerea	0.150841	Fairly deprived	189
2690	Polygon	2691	Dar-es-salaam	Ilala	Segerea	0.150841	Fairly deprived	382
2691	Polygon	2692	Dar-es-salaam	Ilala	Segerea	0.150841	Fairly deprived	381
2692	Polygon	2693	Dar-es-salaam	Ilala	Segerea	0.150841	Fairly deprived	504
2693	Polygon	2694	Dar-es-salaam	Ilala	Segerea	0.270391	Highly deprived	435
2694	Polygon	2695	Dar-es-salaam	Ilala	Segerea	0.270391	Highly deprived	189

0 (0 out of 6743 Selected)

Hex_20minWalkingNet | Residential_Hexagons | Main road | BRTcorridors

Table

Road network

OBJECTID *	Shape *	Walk_speed	Walk_time	Distance_m	Oneway
1	Polyline ZM	71.6667	1.82517	130.804	no
2	Polyline ZM	71.6667	0.698751	50.0772	no
3	Polyline ZM	71.6667	49.6035	3554.92	no
4	Polyline ZM	71.6667	9.97501	714.876	no
5	Polyline ZM	71.6667	3.35474	240.423	no
6	Polyline ZM	71.6667	14.521	1040.67	no
7	Polyline ZM	71.6667	3.38336	242.474	no
8	Polyline ZM	71.6667	10.8975	780.985	no
9	Polyline ZM	71.6667	3.81171	273.173	no
10	Polyline ZM	71.6667	0.816358	58.5057	no
11	Polyline ZM	71.6667	0.495142	35.4852	no
12	Polyline ZM	71.6667	0.755441	54.14	no
13	Polyline ZM	71.6667	2.8913	207.21	no
14	Polyline ZM	71.6667	8.03792	576.051	no

0 (0 out of 94115 Selected)

Table

DART_stops

OBJECTID *	Shape *	Id	Name
1	Point	0	Kimara
2	Point	1	Korogwe
3	Point	2	Bucha
4	Point	3	Baruti
5	Point	4	Kona
6	Point	5	Kibo
7	Point	6	Ubungo_Maji
8	Point	7	Ubungo_Terminal
11	Point	10	Shekilango

1 (0 out of 219 Selected)

Table

Dummy_links

FID *	Shape *	FT_Time (WaitingTime,min)	TF_Time (EgressTime, min)
1	Polyline ZM	3	1
2	Polyline ZM	3	1
3	Polyline ZM	3	1
4	Polyline ZM	3	1

0 (0 out of 163 Selected)

Table

DARTnetwork_route_lines

FID *	Shape *	Route_ID	Route_Name	Distance_btn_Two consecutive stops (m)	Speed (m/min)	Travel_Time (min)
88	Polyline ZM	001	Kimara - Kivukoni	782.623	383.333	2.04163
89	Polyline ZM	001	Kimara - Kivukoni	613.148	383.333	1.59952
90	Polyline ZM	001	Kimara - Kivukoni	513.69	383.333	1.34006
91	Polyline ZM	001	Kimara - Kivukoni	673.876	383.333	1.75794
92	Polyline ZM	001	Kimara - Kivukoni	345.285	383.333	0.900744
93	Polyline ZM	001	Kimara - Kivukoni	365.137	383.333	0.952532
4	Polyline ZM	002	Ubungo - Kivukoni	1285.1	383.333	3.35244
21	Polyline ZM	002	Ubungo - Kivukoni	715.783	383.333	1.86726
26	Polyline ZM	002	Ubungo - Kivukoni	782.623	383.333	2.04163

0 (0 out of 122 Selected)

Table

Job_Locations

FID	Shape *	Job_Counts per Hexagon
1166	Polygon	442
817	Polygon	417
928	Polygon	305
855	Polygon	289
892	Polygon	274
816	Polygon	269
856	Polygon	255
893	Polygon	255
1623	Polygon	249

0

(0 out of 1897 Selected)