ASSESSING POTENTIAL TRAVEL DISPARITIES CAUSED BY NEW TRANSPORT INFRASTRUCTURE IN SUB-SAHARAN AFRICA: AN ABM APPROACH

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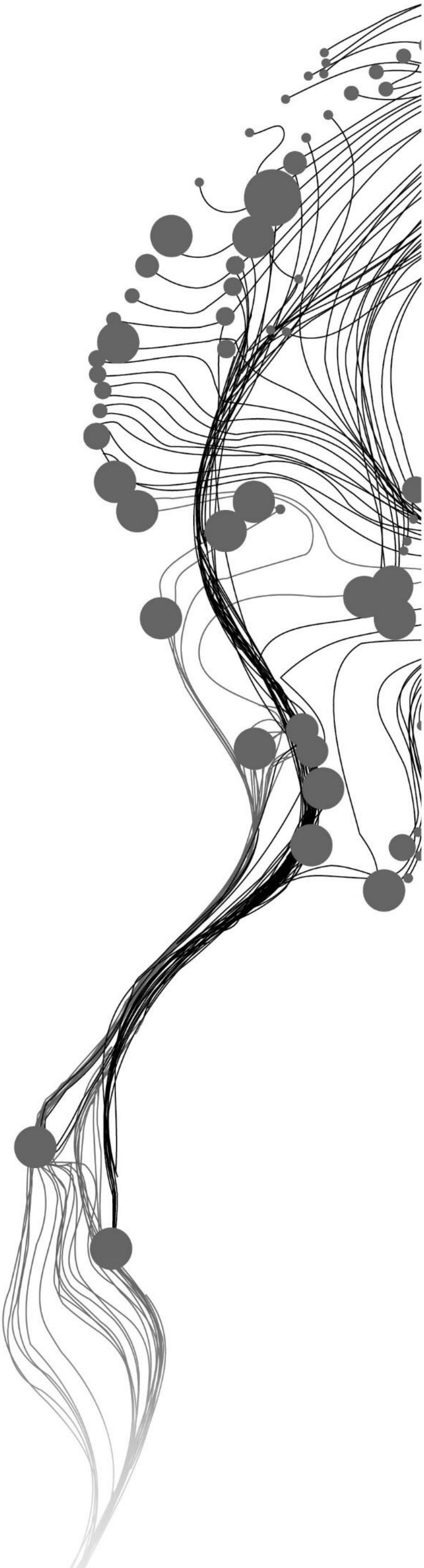

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ABSTRACT

In sub-Saharan Africa, the urban region continues to grow at an unprecedented rate in the population and physical extent, making the movement of information, goods, and people high on the developmental agenda. Precisely, the united nations, through its SDG 11, recognises the high levels of inequality that exist among people of different socio-spatial economic backgrounds. These inequalities in sub-Saharan Africa are significantly high in transportation and take various forms, such as differences in travel time, distance, destination, travel mode, and the number of trips made by individuals. As many governments and transport agencies aim to reduce travel disparities by providing new transport infrastructure, the paradox of reaching a balance between profit and service provision is often unsolved. However, not many studies have been conducted in Sub-Saharan Africa addressing how new transport infrastructure can be implemented to provide a platform for data-driven decision making by policymakers towards transport investment and planning. Further, because of the lack of data and the cost of collecting this data, other alternatives such as Agent-based modelling provide an opportunity to implement and assess the impacts that new transport infrastructure will have on people of different socio-spatial economic backgrounds.

To successfully model these travel disparities, factors that influence Africa's travel behaviour were used to develop and govern agent behaviour in an Agent-based transport environment. The model suggested that new transportation does not necessarily reduce the travel disparities among socio-spatial economic classes but improves the travel behaviour of the lower classes while having the same impact on those in the higher classes. The model also suggests that segregation patterns are critical to inform transport infrastructure suitable for a particular class. However, because the model is stylised, the model needs further development and should be tested with empirical data to make it more realistic.

Keywords: Travel disparities, Segregation, Agent-based modelling, Transport infrastructure, Socio-spatial economic.

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1. INTRODUCTION

1.1. Background and justification

The movement of commodities, information, and people from one location to another has shaped societies. The societies that depend on the locations and flow between activities and the people who create and operate them are configured by the physical networks connecting them (Wise, Crooks, & Batty, 2017). In the Global South, transport networks are primarily centred around motorised transport modes, which leads to significant impacts such as traffic congestion, pollution, and subsequent contribution to climate change (Maggi & Vallino, 2016; Poumanyvong, Kaneko, & Dhakal, 2012). As urban regions continue to grow at an unprecedented rate in the population and physical extent, transport remains high on the agenda.

In addition to the physical impacts of transportation, transport impacts can further be seen in travel disparities among social classes. These travel disparities are differences in the use of an existing or future transport infrastructure identified through travel time, distance, destination, travel mode, and the number of trips made by different individuals (Iglesias, Giraldez, Tiznado-Aitken, & Muñ Oz, 2019; Iroz-Elardo, Schoner, Fox, Brookes, & Frank, 2020; Liao, Gil, Pereira, Yeh, & Verendel, 2020). Travel disparities are also influenced by and reflect the level of accessibility and equity in a transport system. Transport accessibility refers to the degree of ease that land-use and transport infrastructure allows individuals to reach their destinations, while transport equity is the degree of fairness of the transport system for users and transport providers (Van Wee, Annema, & Banister, 2013).

Further, the causes of travel disparities can be linked to three factors that influence travel behaviour: the individual attributes of the users, the location of activities including city form in terms of socio-spatial segregation patterns, and finally, features of the infrastructure supply (Van Wee et al., 2013). For instance, individual preferences, locations of interest, including the ability to make the trip, may differ from one person to another resulting in different travel behaviour. The fact that individual characteristics, location of activities, and features of the transport system are linked also suggests that policy interventions directed towards one aspect influence the other aspects to enhance or suppress travel disparities (Van Wee et al., 2013). Further, because of the dynamic nature of these factors, how they influence travel behaviour, and how users can be amalgamated into homogenous groups, developing transport infrastructure that caters to all users is a challenge for transport providers in places such as Sub-Saharan Africa.

Many governments' immediate solution is to provide new infrastructure to increase motorised modes, reduce travel time and perhaps balance travel disparities (Meijers, Hoekstra, Leijten, Louw, & Spaans, 2012; Melser, 2020). However, the relationship between transport demand and supply is never in equilibrium, and the provision of transport infrastructure is a constant need to balance the demand with the supply. New transport infrastructures can be longer routes, more stations, dedicated bus lanes, bridges, and increased mode choice, also referred to as economic investments (Gnade, Blaauw, & Greyling, 2016; Stupak, 2018). However, governments' continuous adjustment of the transport systems to equilibrium can increase or reduce travel disparities among transport users because transport providers are more focused on revenue generation.

Global organisations such as the U.N. (United Nations), the W.B. (World Bank), the E.U. (European Union), and the AfDB (African Development Bank) have continuously invested in Sub-Saharan Africa's transport infrastructure. For example, in Africa alone, between 2014 and 2016, both global and national investment commitments to transport infrastructure development were estimated at 91 billion U.S. dollars (EXIM, 2018). In most cases, the intention is to enhance economic development and reduce disparity among citizens (OECD & ITF, 2015; Poumanyvong et al., 2012; Snieska & Simkunaite, 2009; Wang, Han, Su, Wan, & Zhang, 2020). However, the creation of new transport infrastructure emphasises the boundary of how and who benefits from the transport infrastructure.

1.2. Methods to assess travel disparities caused by new transport infrastructure

As traditional steps to analysing transport infrastructure's impact on travel behaviour can neglect individual behaviours. Thus, simulation techniques are increasingly being adopted. The commonly used approach is the so-called four-step transport model (FSM), developed in the 1950s to model demand for personal travel (Van Wee et al., 2013). The FSM is a traditional mathematical approach to model and forecast travel demand in four steps: trip generation, trip distribution, modal choice/split, and traffic assignment. The advantages of this method are that it follows a step-by-step approach to model travel demand, making it easier to implement. Additionally, it combines homogenous urban activities into TAZ (Traffic Analysis Zones) to assume that these generate the same types of trips and thus, aggregates travel behaviour to that TAZ. However, this aggregation is one of the limitations of the FSM because it hinders individual travel behaviour's heterogeneity. Also, its dependence on land use classification data, which is not always reliable, is another limitation. Further, Mladenović et al. (2004) highlighted that the model's sequential nature has two main disadvantages; firstly, each step's results are used as input to the next step, meaning that any incorrect assumptions make the whole model unrealistic. Secondly, this sequential approach does not represent the human decision-making process well, which may not always follow the same order as in the four-step model.

Travel behaviour results from individual decisions by different agents possessing independent attributes that govern the decision to interact with the transport system resulting in an independent outcome that varies from one agent to another (Wise et al., 2017). Thus, it requires a more disaggregated approach to understand and model travel behaviour. Agent-based modelling (ABM) is a disaggregated modelling approach that allows for the formulation of these interactions among agents and between agents and their environment (Gallagher & Bryson, 2018). ABM is responsible for much progress in transportation and traffic engineering, as Bazzan & Klügl (2014) summarised. ABM has been used to manipulate and monitor complete system performance in a virtual laboratory. In other words, ABM can emulate the interplays between the transport system and the autonomous agents (Cooley & Solano, 2011). Further, in data-scarce environments, ABM provides a platform to mimic real-life scenarios of the potential interaction and travel behaviours resulting from new transport infrastructure and individual attributes in a stylised way. The ability for ABM to incorporate spatial data such as roads, railway lines, and locations allows for the construction of transport systems to assess how autonomous agents interact with it and the resulting travel behaviours.

ABM's modelling of travel behaviour has been fundamental to research, transport planners, and transport providers. For example, in China, Jing, You, & Chen (2018) used ABM to assess the impact on traffic congestion by parents escorting their children to school. Parents acting as agents based their decision on distance, traffic safety, and social influences to choose between bus and private vehicles. The model includes a decoy effect that suggests that a combination of unattractive alternatives of distance, time, and cost will increase the original mode's choice. The results showed that 62% of parents chose the bus when the decoy effect was not applied; on the contrary, 74% of parents chose the bus in the presence of a decoy. This use of ABM shows how changes in the transport system and individual agents' needs can easily influence travel behaviour. Xiong, Zhou, & Zhang (2018) developed and implemented an integrated ABM and dynamic traffic assignment model to predict and model future travel behaviour changes and traffic conditions. Acknowledging the limitations, the model demonstrated that ABM effectively predicts behavioural responses to changes in a transport system such as departure time, mode, and route adjustments. Both studies reflect the use of ABM in transportation. Even though from the literature reviewed, no model was found that directly considered travel disparities, the studies by Xiong et al. (2018) and Jing et al. (2018) give an example of how changes in the transport environment and the individual characteristics of the agents can be used to model potential travel behaviour.

1.3. Research problem

The UN (2015), through the sustainable development goal 11, emphasise the need to reduce high levels of disparities in its different dimensions among socioeconomic groups. However, in Sub-Saharan Africa, the distinction between the haves and have nots is reflected in how transport infrastructure benefits them. Transport systems should be designed to ensure that all socioeconomic groups have equal access to the infrastructure and services with minimal disparities. As transport providers struggle to provide services, the need to upgrade services for existing transport users are often overtaken by the need to attract new users for revenue generation as transport infrastructure is considered an economic investment (Manaugh, Elgar, & London, 2012). By focusing on revenue generation, travel disparities can be created for existing and new users based on their socioeconomic backgrounds. Understanding how new transport infrastructure affects different socioeconomic groups is essential to ensure equal use and reduce disparities.

1.4. Research objective

This study was built on existing knowledge on travel disparities in transport infrastructure investment in Sub-Saharan Africa. In particular, the study constructed and used a stylised ABM to simulate the potential travel disparities resulting from new large transport infrastructure at individual and group levels while considering various levels of socio-spatial segregation.

1.4.1. Research objectives and sub-objectives

Research objective 1: Identify factors that influence travel behaviour in Sub-Saharan Africa.
1.1 What prominent factors influence travel behaviour, particularly in the Sub-Saharan African context?
1.2 What is the level of Socio-spatial segregation in cities in Sub-Saharan Africa?

Research objective 2: Conceptualise and implement an ABM model that includes the attributes and interactions among agents and between agents and the transport environment in Sub-Saharan Africa.
2.1 What are the type of agents and the attributes that govern their decision-making process towards travelling?
2.2 How does the environment in the model look like?
2.3 What are the likely interactions among the agents and the transport infrastructure at the individual and group levels?
2.4 Which outcomes of the model can be used to measure travel disparities?

Research objective 3: Use the developed ABM model to simulate different scenarios and discuss travel disparities.

3.1 What is the travel behaviour of agents in an existing transport system given various levels of segregation?
3.2 What is the travel behaviour of agents after the new transport infrastructure is introduced in the transport system, given various levels of segregation?
3.3 What travel disparities are observed in travel behaviours of agents in existing and new transport system?

1.5. Thesis structure

The structure of the thesis is as follows:
Chapter 1 introduces the study by giving the background and the research objectives and sub-objectives. **Chapter 2** is the Literature Review, and it explains how new transport infrastructure affects travel behaviour through existing studies. Additionally, it highlights travel behaviour in Sub-Saharan Africa. **Chapter 3** is the methodology, and it explains in detail the approach taken to achieve the objectives. **Chapter 4** gives the conceptual framework of the model as elaborated and conceptualised by the ODD protocol. **Chapter 5** is the results of the Model, and it explains the analysis of the model results. **Chapter 6** is the Discussion, and it discusses the model results, the expected and unexpected outcomes, including the model's limitations. Finally, **Chapter 7** is the conclusion, and it provides a summary, conclusion of the thesis and areas of focus for future studies.

2. LITERATURE REVIEW

2.1. Factors influencing travel behaviour

Factors that influence travel behaviour can be grouped into three categories: individual characteristics, the location of activities (land-use characteristics), and factors related to the physical characteristics of the transport system as defined by Van Wee et al. (2013).

In the first category, general factors such as income, age, car ownership, time, cost, sex, house size, lifestyle, personal preferences, attitudes, including medical conditions, relate to the individual. For example, people with high income are likely to afford a car or make frequent and longer trips than those with less income, but then again, factors like time may not allow them.

In the second category, the location of activities is essential in the movement of goods and people because they define destinations where people satisfy their needs. Transport is a means and not an end and is a disutility to users whose utility is at the destination. The distribution of activities often framed in land-use planning and urban form influences transport volumes, demand, and time. Land-use patterns and their functional relationship with residence, work, services, education, shopping, and entertainment largely influence where and when people want to go. The theoretical determinants of land use, such as density, mixed land use, neighbourhood design, and distance of origins and destinations to public transport, are crucial to understanding how land use influences transport. See Table 1.

In the third category, Van Wee (2013) discusses travel behaviour in the context of the transport system's physical characteristics. The elements here include travel time, cost, comfort and safety, and the summation of these elements is often referred to as the generalised transport cost (GTC). With less generalised transport cost, results in more and longer trips by people. However, the generalised transport cost is determined by the transport infrastructure's quantity and quality; thus, in transport planning and investment, a balance has to be met between an acceptable GTC and good transport infrastructure. Further, the attractiveness of a location also influences the GTC. For instance, employed people have no choice but to overcome the GTC to reach employment locations.

Several authors and researchers allude to the relationship between transport systems and the users' socioeconomic characteristics in influencing travel behaviour. Travel behaviour is distributed differently among people with different attributes such as income, age, employment status, and activities (Heinen, Panter, Mackett, & Ogilvie, 2015; Van Wee et al., 2013). For instance, individuals with more income generally make more trips because they may have a vehicle or spend more money to reach activities than those with less income. In Santiago de Chile, groups in the upper-income quantiles generated 1.6 times more trips than those in the lower quantiles. In addition, the upper-income quantile benefited 2.5 times more than those in the lower-income quantile when new transport investments were placed (Iglesias et al., 2019).

Table 1 Land-use determinants and their influence on travel behaviour, adopted from Van Wee (2013)

Sn	Land-use transport Determinants	Brief Description
1	Density	Density refers to the number of opportunities, i.e., dwelling spaces, households, people, and jobs per square km. The higher the density, the more opportunities concentrated in one place, the shorter the trips, and slower travel modes may be chosen.
2	Mixed land use	Refer to the degree of mixing land-use types such as dwellings, workplaces, shops, schools, and medical services. It influences how people travel. For example, a high level of mixed land use can be related to short distances and slower modes of transport and vice versa
3	Neighbourhood design	Neighbourhood design refers to the general layout of the neighbourhood at its largest spatial scale. This refers to things like distance to the parking spaces, walkability, play parks, bicycle shade. In other words, an attractive neighbourhood might encourage people to walk or cycle more and use fewer motorised vehicles.
4	Distance to public transport connections such as bus or train stations	Suppose more opportunities and activities such as jobs and dwellings are located near a bus or a train station. In that case, it increases proximity access and reduces egress time, thus increasing public transport use.
5	Interaction between determinants	The determinants in certain circumstances can induce and interact with each other; for example, high-density neighbourhoods near a train station can encourage mixed land use and further densification within that area.

In Toronto, transit provision showed that travel disparities between different income groups narrowed between 1996 and 2006, making the transport system more equitable and accessible for most (Foth, Manaugh, & El-Geneidy, 2013). Manaugh et al. (2012) assessed how new transport infrastructure influenced the travel time of socially disadvantaged groups. The disadvantaged neighbourhoods were identified based on income, immigration status, education levels, and employment status. Travel behaviour based on travel time was compared before and after a new transport infrastructure. The results showed that some neighbourhoods had improved travel time while others still had elevated travel time. Heinen, Panter, Mackett, & Ogilvie (2015) studied the impact of a new guided busway, cycling, and walking lanes on congestion. The results indicated that approximately 3.4% of the sample population, between 2009 and 2012, changed from using private vehicles to more active modes such as walking and cycling, while 2.3% of transport users rotated between cycling, walking, and bus. Such an analysis explains the effects that new transport infrastructure can have on travel behaviour. It further suggests that mode choice is one indicator that can be used to measure travel disparities.

2.2. Travel behaviour in Sub-Saharan Africa

Travelling for most people in Sub-Saharan Africa is an ever-increasing challenge; however, studies discussing and investigating travel disparities in this context are scarce. Sub-Saharan Africa has a significant proportion of the population living below the poverty line and in slums. This type of society does not always conform to the commonly understood influencers of travel behaviour, such as time, cost, and speed (Salon & Aligula, 2012). Most people depend on public transport, which is supplied by multiple private businesses whose main aim is profit-making rather than service provision. For some, travel behaviour is not influenced by high prices but lack of adequate service provision and safety (Sohail, Maunder, & Miles, 2004). However, other studies have suggested that the gap between public transport cost and income levels in places such as western Africa remains a significant obstacle and an influencer of travel behaviour (Godard, 2013). Transport users, especially from low-income families, resort to walking and cycling long distances in challenging transport environments, making travel disutility very high (Tembe, Nakamura, Tanaka, Arioshi, & Miura, 2020). The factors that influence travel behaviour in the region show minimal variation (Godard, 2013; Tembe et al., 2020). However, transport investment that caters for all users is still a challenge (EXIM, 2018). For example, a comparative study of travel behaviour between Maputo and Nairobi showed that factors such as gender had little to do with choosing a non-motorised mode, while income, car ownership and age played a huge role (Tembe et al., 2020).

In the Sub-Saharan region, transport investment is centred on building roads and upgrades compared to investment into public transport and customer service (Jones et al., 2016). This approach can be disadvantageous to the poor because it forces them to use unsafe cheap modes to reach activities. The problem of limited information on travel patterns, disparities and impacts of new transport infrastructure in Sub-Saharan Africa presents a challenge for both users and transport providers. The lack of understanding of the impacts of new transport infrastructure on travel behaviour prevents identifying investment areas.

2.2.1. Transport infrastructure in Sub-Saharan Africa

In Sub-Saharan Africa, the transport environment is dominated by private cars and minibuses that carry 8-25 passengers, while larger buses that have 30-50 passenger capacity are used for intercity trips. Motorcycles and taxis are also another mode of transport in places such as Nairobi (Kumar & Barrett, 2008; Salon &

Gulyani, 2010). Additionally, the quality and features of the routes influence travel in different ways. For example, in Maputo, Lusaka, and Nairobi, 65% of the transport network is missing pedestrian ways such as cycling and walking lanes which discourages walking and cycling (Kumar & Barrett, 2008). Further, approximately less than half of the roads are paved, with reduced bus accessibility, no proper street lighting, and most roads are one laned. In cities such as Dakar and Ouagadougou, 60 % of the roads are in a poor state, impacting females and school-going children's travel behaviour because of lack of safety (Venter, Vokolkova, & Michalek, 2007). In South Africa, where road capacities for private and public modes are better than most Sub-Saharan African urban cities, the average travel times are high. Hitge & Vanderschuren (2015) records that bus travel on average during peak hour last for 53minute while for private cars is around 40 minutes on a typical trip.

Most cities do not operate light trains within the city. In Nairobi, the light train is less than 2% of the transport system (Kumar & Barrett, 2008). Further, the transport fare is based on the total distance travelled and not calculated by the unit of distance (Salon & Aligula, 2012). Additionally, congestion is a problem, especially during rush hour, which leads to extended time on the road. In Douala and Conakry, the city's average daily travel time is one hour and thirty minutes because of heavy congestions (Diaz Olvera, Plat, & Pochet, 2013).

2.2.2. **Location of activities in Sub-Saharan Africa**

Urban cities of developing countries are continually growing in population and boundary, expanding around a CBD (central district board) (Kumar & Barrett, 2008). Land-use types such as commercial, residential, and industrial characterise this urban growth (Kumar & Barrett, 2008; Venter et al., 2007). Most activities are centred around commercial locations, with the poor pushing towards employment locations to reduce walking distance, time, and travel costs. Thus, the location of activities is closely related to the city form concerning socio-spatial segregation patterns, which are common in Sub-Saharan Africa.

2.2.2.1. Socio-spatial segregation in Sub-Saharan Africa

In general, socio-spatial segregation prevents certain socio-groups from accessing infrastructure, services, job opportunities, including contact with other social groups by marginalising, stereotyping, depriving, excluding, or isolating them. Socio-spatial segregation is the extent to which individuals of separate groups are prevented from occupying or experiencing certain social and physical aspects of their environments (Reardon & O'Sullivan, 2004; Schnell, Abu, Diab, & Benenson, 2015). Spatial segregation is observed when group members are not distributed uniformly in a residential space in relation to the rest of the population. There are five spatial segregation dimensions: Evenness, Isolation, Concentration, Centralisation and Clustering that can be used to measure the degree of spatial segregation (Massey & Denton, 1988). Socio-spatial segregation prevents people from accessing transport infrastructure due to their physical location

(Reardon & O'Sullivan, 2004). Additionally, as spatial segregation is linked to individuals' socioeconomic traits, the relationship to travel behaviour can be observed in the similarity of travel behaviour displayed by individuals in the same group.

In sub-Saharan Africa, spatial segregation is influenced by individuals' socioeconomic status, even though studies that measure socio-spatial segregation using quantitative indices are rare. In infrequent circumstances, social and spatial segregation are mutually exclusive. Smiley & Koti (2010) identified qualitative and quantitative indicators that can be considered in measuring social-spatial exclusion; these include income status, social class, gender, race, ethnicity, occupation, or age. However, spatial segregation is most visible in the landscapes that shape most urban cities, such as gated communities and slum areas. Poverty is a major underlining component of spatial segregation (Venter et al., 2007). In areas such as Durban of South Africa, poverty coupled with racial elements are critical influencers of spatial segregation rooted in colonial times, such as during Apartheid (Durrheim, 2005). However, because of the cultural background of South Africa, racial segregation is not common among most countries of Sub-Saharan Africa as compared to poverty.

Poverty has caused people to be spatially segregated into classes such as the High-class comprising individuals and households with highly paid and fancy live-in neighbourhoods, middle class who are middle earners in society. They are not lacking as the lower class but not creamy as the high class and are usually in salaried employment. While the lower class comprises the poor, who are often below a defined poverty line (Henning Melber, 2015).

The high-class social group holds the highest status and are wealthy. The AfDB (2011) categorises the high class to be in the income range greater than 20 U.S. dollars per day, and it is 18.8% of the population. On average, this translates to an annual income of more than 7300 US dollars. This group is usually located in gated communities, in the city's periphery or isolated expensive neighbourhoods. They have the best access to employment, health, schools, entertainment, including transport infrastructure and high car ownership. Further, the family structure is much smaller than the other socio-economic classes, such as the lower class in household size than the average of 6.9 across Africa (United Nations Population Division, 2017).

The AfDB (2011), the middle class, falls within the 20th and 80th percentile of consumption or translated from 6 U.S. dollars to 10 U.S. dollars daily capita. Additionally, these are people that have an annual income exceeding 3900 US dollars. This class makes up about 44.7 % of Africa's population. These are concentrated in urban areas with good access to schools, health care, transport infrastructure, and smaller families than the low class. This group has a household size around the average household of 6.9 in sub-Saharan Africa (United Nations Population Division, 2017).

The lower class is characterised by an income range of less than 2 U.S. dollars and makes up 36.5 % of the population defined by the AfDB (2011). These are the people and households that leave close to employment areas to reduce distance, especially industrial areas to make it more manageable to walk to reach such destinations, as travel costs can be high (Kumar & Barrett, 2008; Venter et al., 2007). However, accessibility is a challenge to transport infrastructure. Additionally, this group has the largest household size, typically over 9 through 16 people (Eloundou-Enyegue & Williams, 2006; United Nations Population Division, 2017).

The socio-spatial classes were well represented by the U.N model of an African city in Figure 1. With classes distributed differently in a hypothetical city mainly at the core of the CBD, primarily commercial areas with a mix of residential areas. While the immediate two rings represent the middle class characterise the indigenous and mixed, the third ring is for the elite who can be classified as the high class. In the last patches, referred to as the shanties, this is occupied by the low class. Even though this model was presented in 1973, and African cities have evolved, it is helpful to represent how socio-spatial segregation is formulated visually. The evolution of African cities may be within the defined socio-spatial segregation pattern by Massey & Denton (1988), who identified evenness, concentration, and clustering as segregation measures. For further explanation on this see (Massey & Denton, 1988).

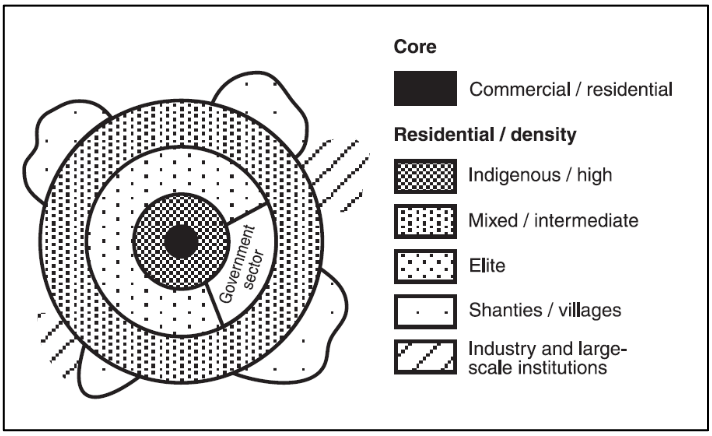

Figure 1 African city model depicting the socio-spatial segregation.
Source: United Nations (1973) land policies and land-use control measures volume 1 New York

2.2.3. **Individual characteristics in Sub-Saharan Africa**

In Sub-Saharan Africa, one of the factors that influences travel behaviour is economic dimensions. For example, income as one of the individual attributes that influence travel behaviour appears several times in the literature (Godard, 2013; Kumar & Barrett, 2008; Salon & Aligula, 2012; Tembe et al., 2020). On average, families can afford one daily bus trip, close to zero for the poorest. In Nairobi, 80% of Nairobi residents have one member that uses motorised transport; however, twice as many trips are taken by Minibuses than larger buses and private cars (Kumar & Barrett, 2008; Salon & Gulyani, 2010).

Further, because most people cannot afford motorised transport, proximity to employment is critical. Thus, the poor live near commercial areas in slums and unsafe environments (Salon & Aligula, 2012; Salon & Gulyani, 2010). In Conakry, Dakar, Niamey, and Douala walking comprises the transport mode (Diaz Olvera et al., 2013). Additionally, as stated previously, comfort, safety, and travel reliability are also important aspects that influence travel behaviour (Salon & Aligula, 2012; Sohail et al., 2004). In the context of gender, more men use motorised transport modes than women. This can be linked to job opportunities with men, by proportion, dominating employment status (Diaz Olvera et al., 2013). See Table 2\

Table 2 Summarizes factors influencing travel behaviour in Sub-Saharan Africa

Category	Factors influencing travel behaviour	Country or city	Source
Transport infrastructure	• Type of Motorised transport (Bus, cars) • Capacity of transport • Bus fare or cost of travel	Kenya Nairobi	(Kumar & Barrett, 2008) (Salon & Gulyani, 2010)
	• Presences of sidewalk and cycling lanes	Maputo, Nairobi, and Uganda	(Kumar & Barrett, 2008)(Porter, 2002)
	• Design of transport infrastructure; Distance to public transport stops and stations and roads usually are one laned. • Safety and comfort	Dakar and Ouagadougou	(Venter et al., 2007) (Kumar & Barrett, 2008)
	• Transport fare which is based on distance or travel time	Douala and Conakry	(Diaz Olvera et al., 2013) (Salon & Aligula, 2012)
Location of activities	• Distance to location (Determines the travel cost and the type of mode for travel)	Nairobi,	(Venter et al., 2007) (Kumar & Barrett, 2008)
	• Residential, commercial, and industrial areas are destinations and origins of trips.	Maputo, Nairobi	(Venter et al., 2007) (Kumar & Barrett, 2008)
Individual attributes	• Income (Strongly influences the ability to make trips using motorised modes)	Dakar and Abidjan, Nairobi, Maputo	(Godard, 2013; Kumar & Barrett, 2008; Salon & Aligula, 2012; Tembe et al., 2020).
	• Vehicle ownership (On average, one member uses a motorised vehicle)	Nairobi, Maputo	(Salon & Aligula, 2012; Sohail et al., 2004).
	• Gender: (Women and children mostly walk, more man uses motorised transport)	Conakry, Dakar, Ouagadougou, Niamey, and Douala	(Diaz Olvera et al., 2013)

The literature review identified elements of travel behaviour that were drawn from the general literature. The general literature review informed the literature review of the factors that influence travel behaviour in Sub-Saharan Africa, summarised in table 2. The review further identified differences that are multi-scalar. For example, in other countries, gender and safety influences travel behaviour, while generally, in Sub-Saharan Africa, this was not the case. Factors such as income, travel cost, employment, vehicle ownership, location distance, and activities were constant. However, it was not so clear as to what unit was used to calculate the travel cost.

Further, the literature review was informative to identify which kinds of studies are related to the study area. Generally, it was observed that studies conducted in developed countries that included both empirical and qualitative approaches were more prevalent because of data availability through mobility surveys. The studies used actual data acquired over a long time before and after the new transport infrastructure. These approaches are mainly applicable when understanding how the implemented transport infrastructure affected travel behaviour. While in Sub-Saharan Africa, the studies that were reviewed were qualitative. One of the reasons for the lack of quantitative studies was the lack of empirical data such as travel diaries from mobility surveys.

3. RESEARCH DESIGN AND METHODOLOGY

This study aims to assess whether travel disparities arise from new transport infrastructure among individuals of diverse socioeconomic backgrounds in Sub-Saharan Africa. Figure 2 shows the summary of the methodology and sequence of steps used to achieve the study's primary objective.

3.1. Literature review

The initial step was to understand the different elements of travel behaviour by assessing existing scientific knowledge on transport behaviours in Sub-Saharan Africa through a literature review. This process was not informed by fieldwork; rather, a literature review informed aspects of the stylised ABM, such as the synthetic population's attributes, the transport system, and the location of activities.

3.2. Purpose of approach

Modelling presents numerous opportunities to solve transport problems and inform decision making. Specifically, in the absence of data and time constraints, abstract or stylised models can be used to forecast, predict and analyse problems. Thus, for this reason, and those mentioned in the previous chapters, a stylised ABM approach was used to incorporate individual attributes, behaviours, and rules that govern transport users at an individual level and their interaction with the transport environment to assess the travel disparities. Additionally, this approach was suitable in building multiple scenarios of what can be to understand better the resulting impacts of transport infrastructure change on travel behaviour. Further, when the covid 19 pandemic was at its peak at the time of the research formulation, a stylised modelling approach was the better choice to investigate the travel disparities caused by new transport infrastructure.

3.3. Input variables

Two types of literature reviews were used to inform the input variables. The first literature review highlighted the generalised categories and factors that influence travel behaviour, as explained in section 2.1. The first literature review was necessary to compare which categories and types of factors were essential to measuring travel behaviour. The output of this approach was three categories of factors that influence travel behaviour, i.e., the factors that relate to the transport system, the individual attributes such as wants, preferences and needs, and finally, the location of activities.

In the second literature review, literature specific to Sub-Saharan Africa transport behaviour was reviewed to understand the characteristics and factors that influence travel behaviour in sub-Saharan Africa. The output factors that influenced transport in Sub-Saharan Africa placed in the three categories identified in the first literature review. For a summary, see Table 3. However, to reduce the model complexity, factors cited twice or more in Sub-Saharan studies were selected for further processing. Another filter that was considered was the variables' spatial diversity in terms of the number of cities with similar factors.

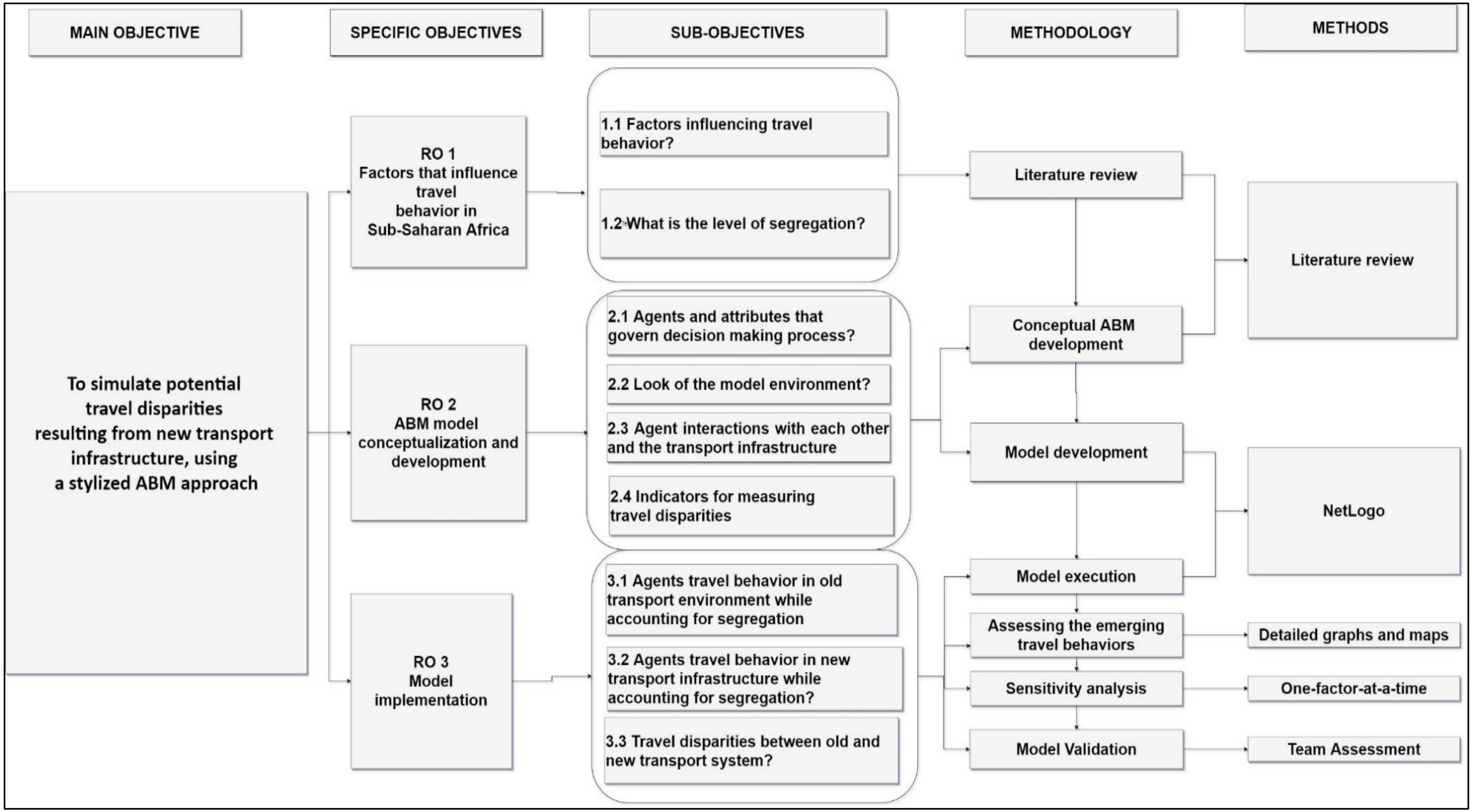

Figure 2 Methodology for the study

In the case of land use, although few authors mentioned land use, this variable was crucial to the transport environment setup.

Table 3 Summary of model input variables from the literature review placed in three categories.

Sn	Category	Model input variables	Description and Motivation
1	Transport infrastructure	Cost of travel	The cost of travel defines the resistance that people will have to reach destinations. In the present study, the cost of travel sums up the monetary cost of travel, the duration of travel, and in the case of public transport, it also includes waiting time at the station and the time to reach the station.
		Mode	Type of transport mode available to the agents, i.e. motorised car, bus, and implicitly non-motorised, i.e. walking
2	Location of activities	Land-use	The land use allows for the identification of the origin and destination of the trips. In the case of work-related trips, the land use type commercial and residential, were considered.
3	Individual attributes	Car ownership	This variable influences the number of trips, cost and time of travel and is also related to income. For instance, in Maputo and Nairobi, the probability of using the bus reduced with car ownership and employment status.
		Household income	The income shows the ability of persons to make trips using a motorised transport mode. The income also related to the number of trips that persons can make. For instance, the higher the income, the more the motorised trips.
		Employment status	Work-related trips of employed and unemployed persons are considered.

3.4. Conceptual ABM and model development

The literature review was used to inform objective 1. The output of the literature review was used as a basis for the conceptualisation of the model using the ODD (Overview, Design concept, Detail's protocol). It is an approach to develop a consistent, logical, readable, and understandable structure of the ABM, usually in text form that humans can understand (Grimm et al., 2020); see chapter 4. The ODD protocol has three significant steps the Model Overview, Model design and Model details. These are then divided into seven steps: as seen in Table 4. The overview step briefly identifies the model purpose and its properties, including the process description. The Design concepts inform the concepts that govern the model in its implementation. The Details section guides the model's technical aspects, including the model set up, input variable and data, and sub-models if applicable.

The ODD protocol groups model development into three categories, as seen in Table 4. Further, the ODD protocol assists in explaining how the intended model output can be measured, which in this study, the aim is travel disparities.

Table 4 The ODD Protocol and its steps

SN	STEP	ELEMENTS OF THE STEPS
1	Overview	1.Purpose
		2. Entities, state variables, and scales
		3.Process overview and scheduling
2	Design Concept	4. Design concept
		Basic Principles
		Emergence
		Adaptation
		Objective
		Learning
		Prediction
		Sensing
		Interaction
		Stochasticity
		Collectives
		observation
3	Details	5. Initialisation
		6. Input data
		7.Sub-models

Source: (Grimm et al., 2020)

3.5. The ABM computerised environment

In this section, the conceptual model was converted into a computerised environment using NetLogo (Wilensky, 1999). NetLogo is a multi-agent programming language and modelling environment suitable for modelling complex systems by giving instructions to individual agents that simultaneously execute the instruction to assess the relationship between micro and macro levels. Because transport systems are heterogeneous and complicated, especially that they contain human agents with autonomous decision-making capabilities, NetLogo presents a simple yet meaningful environment to model potential travel disparities that result from new transport infrastructure. An alternative option was to use an existing ABM and adapt it to this study; however, seeing that the available models are limited and could be much easier to build a new model, the alternative option was not considered.

3.5.1. **Analysis**

The model simulations are divided into two parts. The first part assesses the model sensitivity in the old transport infrastructure without the new transport infrastructure, as discussed in the passages below. The second part of the analysis runs the simulations with the new transport infrastructure and assesses the influence of the segregation patterns.

3.5.1.1. Sensitivity Analysis

In the development of ABM, where the model parameters are not available, defining agent parameters that meet real-life scenario is challenging. In the absence of actual data that inform agent behaviour and interaction with the transport infrastructure, as is the case in this study, model parameters were estimated based on available figures on travel behaviour and qualitative descriptions in literature in Sub-Saharan Africa. Thus, a sensitivity analysis was necessary to conduct (Niida, Hasegawa, & Miyano, 2019). A sensitivity analysis is a procedure used to test for model robustness by observing the variations in the output when one or more parameters are changed (Burgers, Hofstede, Jonker, & Verwaart, 2010). This procedure can help identify critical parameters to the model dynamics (Niida et al., 2019). Thus, in this study, the one-factor-at-a-time approach was used. This approach assessed sensitivity by changing one parameter while keeping the rest of the parameters constant to investigate how the model behaves. Specifically, in this model, multi-linear regression was used to assess the model sensitivity. See Table 5 for the setting of the model during the sensitivity analysis. The model was run for 30-time steps, with ten repetitions for each combination of parameters, which resulted in 5760 runs in the behaviour space. The behaviour space is an inbuilt automated Netlogo tool used to perform a vast number of experiments in an automated manner by systematically varying the model parameters setting and recording the results (Wilensky, 1999). Further, the simulation run for the sensitivity analysis was conducted in three types of segregation measures as explained in section 2.2.2.1: Evenness, Concentration, and Clustered. In this study, these were termed as Random, Centric and Clustered socio-spatial segregation, respectively. Further, the sensitivity analysis was run in the old transport infrastructure while the New routes and new stations were turned off (False in the model setting).

The outputs from behaviour space were then empirically processed in SPSS using the "force entry method", which allows predictors to be entered into the statistical model with the same hierarchy. Only the 30th step of the simulation was used in the linear regression because the model was concerned with the final results from the impact of transport infrastructure change. Specifically, the regression investigated the correlation of the independent variables to the key outputs by investigating the correlation values. The multicollinearity among the predictors was tested using tolerance and VIF, with the results being acceptable if the tolerance was greater than 0.2 and the VIF < 10 with P-value < .05 was desirable.

Table 5 Initial parameters in the Sensitivity analysis

SN	PARAMETERS	VALUES
1	Waiting time bus station	True False
2	Walking time to station for bus users from home	True False
3	Segregation	Centric Random Clustered
4	New routes	False
5	New stations	False
6	Travel cost (car and bus)	True False
7	Travel budget	True False
8	Time to Station for car users	True False

Additionally, the beta values were used to explain each predictor's contribution to the dependent variable. The power of the predictors to reliably predict the dependent variables was assessed using the F-value and the p-value, which were all significant (Field, 2009). However, some predictors were not significant towards certain independent variables; for example, walking time to station and in-car time was not significant towards predicting the mean travel budget.

Further, some parameters' stochastic nature resulted in multiple variations in the results from the same settings. To mitigate the randomness of the model, the model was run ten times with the same settings and then means, standard deviation, maximum and minimum values were recorded and analysed. This was done to assess to what degree the model randomness affected the results.

3.5.2. **Simulating the impact of transport infrastructure changes**

Table 6 shows the type of transport infrastructure changes that were made in the model. Three considerations informed the transport infrastructure layout: Firstly, a simple starting transport infrastructure that can be expanded to increase complexity—secondly, an alteration to the transport infrastructure that increased accessibility by reducing proximity—lastly, a change to the transport infrastructure that could be considered a large transport infrastructure implementation. Figure 3(A) shows the layout of the old transport infrastructure, (B) shows the layout with the new routes, while (C) shows the layout of the transport infrastructure with the new stations. Additionally, in reality, routes have different lengths and capacity constraints, e.g., number of lanes, max speeds allowed, and traffic lights that influence travel. However, the infrastructure in the model is assumed to be simple, with two lanes, no traffic lights, and the same speeds across all route segments, which are all accounted for in the variables travel time and route capacities of the transport infrastructure.

Table 6 shows types of infrastructure change made

Change	Current State	Updates in the model
Additional route	Some stations are not linked	Ring road
Bus stations	Four residential stations One commercial station	More bus station to increasing accessibility More Routes that also connect the new stations

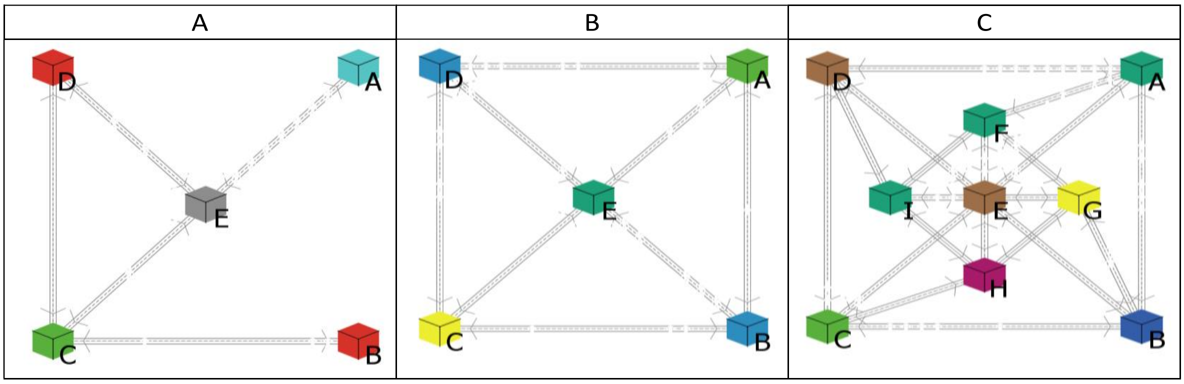

Figure 3 Transport infrastructure layout; A old transport, B new routes and C new routes and stations

3.5.2.1. New transport infrastructure analysis

After completing the sensitivity analysis of the model, the actual simulation to investigate the travel disparities caused by new transport infrastructure was run in three steps. The first simulation involved running the model for 30 steps in the old transport infrastructure. Then the same procedure was run with the addition of the new routes see figure 3 (B), and finally, the new stations were added as in figure 3 (C) at the same time, keeping the segregation pattern constant.

3.5.3. **Segregation patterns**

The segregation patterns used to investigate the influence of segregation on travel behaviour included Random, Clustered and Centric. These were informed by Massey & Denton (1988) and the UN African model of 1978. The model African city of 1978 resembles the centric segregation in the model; however, since 1973, African cities have evolved; and display various forms of segregation. Thus, random and clustered segregation patterns were necessary to assess the various forms and their impact on travel behaviour, as seen in figure 4.

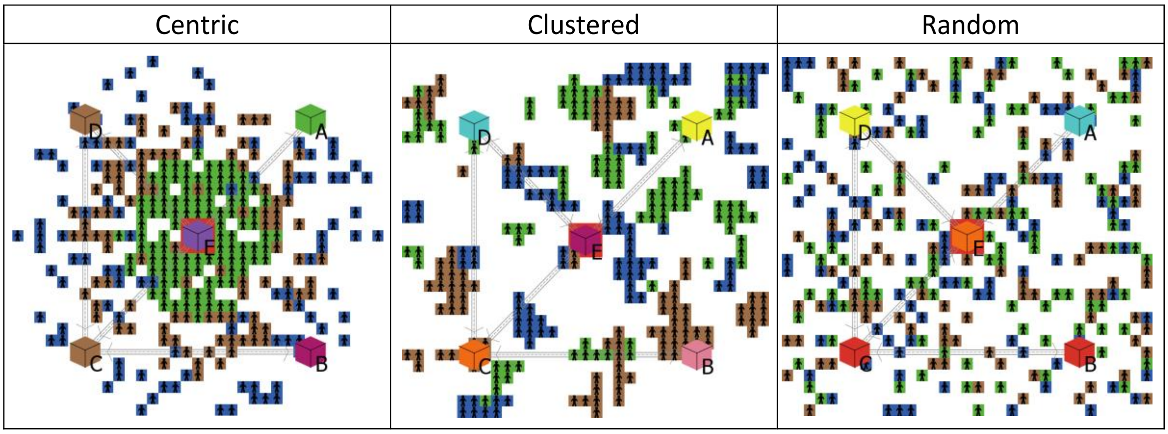

Figure 4 Variations of Socio-spatial patterns of patches

3.5.4. **Formulating Results**

The sensitivity analysis results and the actual analysis were processed by eliminating unnecessary columns and rows of data in preparation for the analysis and visual presentation using tables, boxplots, and maps in Excel, SPSS and ArcMap. Further, the result presentation included highlighting results of interest that were vital to explaining the outcomes from the model.

3.5.5. **Model validation**

One of the components of effective modelling is ensuring that model simulations produce the correct results through validation. As defined by Carson (2002), validation ensures that the model parameters, processes, and output represent the real world accurately from the perspective of the model's intended use. Sargent (2010) identifies four basic approaches that can be used to assess model validity. The first approach is the validation by the modelling team based on the model purpose and results. This approach includes conceptual model validation, operational validation, and data validity. In the conceptual model validation, the assumptions and model characteristic correctness is checked. In operational model validation, the model output behaviours are checked to align with the model's intended purpose. The data validation process ensures that the model data inputs are correct for testing, simulation, and model results.

The other approaches not used in this model development process involve having the model users use the model and validating it according to their needs. Thirdly, validation by understanding the model's purpose, conceptualisation, development process, and detailed results by an external party. The fourth approach is not commonly used but involves using a scoring model; for an in-depth explanation of this approach, see Balci (1989).

Thus, in this study, the priority model validation approach was the modeller's assessment. This validation procedure was done at each step of the model conceptualisation and development. Even though this approach can be biased, it is employed in this MSc research because it is more time-efficient and has no financial implications.

4. CONCEPTUAL MODEL FRAMEWORK

This section describes the model framework in the ODD protocol described by Grimm et al. (2020). Each concept is answered by answering specific questions.

4.1. Overvie

4.1.1. Model purpose

4.1.1.1. What is the purpose of the model?

The model aims to investigate potential travel disparities among people caused by new transport infrastructure.

4.1.1.2. Who is the model for?

The model is designed for scientist, and the model results for policymakers in Sub-Saharan Africa during transport planning and investment to enhance inclusiveness and reduce travel inequalities.

4.1.2. What entities do what, and in what order?

4.1.2.1. What kinds of entities are in the model?

The model has three types of entities: The Agents, the Links, and the Stations. In the model, agents represent people who use the transport infrastructure to reach destinations. The classes have additional attributes (see next section) that govern each agent's decision-making process, and they vary from one class to the other. The links represent roads that connect stations and the commercial and residential patches. The stations are points joining links where agents go to access the transport infrastructure. The bus users use the stations as bus stations, while the car users use the stations as access points to the transport infrastructure. The links and stations make up the transport infrastructure.

4.1.2.2. By what state variables, or attributes, are these entities characterised?

The agents have the following attributes: Income (estimated values for the Low-class, Middle-class, High-class), car ownership, and employment status. See table 9. Additionally, the links have variables for travel time per mode, travel cost per link mode and capacity of the link, which is the maximum number of trips users that the route can accommodate. While the stations have the variable waiting time at stations which is the time used on average, people would spend at a bus station. Further, the stations have a variable name that identifies the station. See also Table 10.

4.1.2.3. What are the exogenous factors/drivers of the model?

The exogenous factors of the model are the changes that are made to the transport infrastructure. These changes include a ring road and five different bus stations in the initial model, then four more stations and routes join them in the new transport system.

4.1.2.4. If applicable, how is space included in the model?

There are two ways space is utilised in the model. The first is the residential patches representing where agents live, while the second is commercial patches which are the destinations of the trips. However, since the model is stylised the spatial extent of the model does not influence the model results. In reality it takes a person 15minutes on average to walk a distance of 1km (Inani Azmi, Abdul Karim, & Zamreen Mohd Amin, 2012). Since the model assumes a small city with only 1023 patches, in the model it is assumed that it takes persons to walk from one patch to another a total time of 7 minutes, while for cars, it takes 3.5 minutes.

4.1.2.5. What are the temporal and spatial resolutions and extents of the model?

The temporal scale of the model is one month. Therefore, every tick represents a time step of 1 day, and the model is run for 30 steps to represent one month. The model stops running for each simulation at the end of 30 ticks, and the outputs are recorded. The model has 1023 patches.

4.1.3. Process overview and scheduling

4.1.3.1. Who (i.e., what entity) does what, and in what order?

There are two steps in the model, which include the initialisation and the simulation.
At tick = 0, when the setup is executed.

1. The landscape is created with each patch representing residential or commercial land use, and the residential patches are divided into Low, Middle, and High socio-spatial economic classes.
2. Then the creation of the stations and directed links that connect the stations.
3. The links and bus stations set the capacity, travel time per mode, travel cost and waiting time at the station.
4. Then on each residential patch, one person is created.
5. The persons set travel mode between car or bus set to true or false.
6. When the “go” button is executed, the bus and car users jump to the nearest station.
7. The links then set the impedance of travelling per individual agent.
8. The persons then assess which route and mode have the least impedance to reach the destination and use it.

9. The persons make one trip from residential to commercial patch and jump back to the residential patch
10. When the process is complete, the tick is increased by 1.

4.1.3.2. When are state variables updated?

All variables are given random values at the setup of the model as established from the literature review in Chapter 2. See also table 9,10, and 11. In the model, the tick is put at the end of the "Go" procedure. The "tick" is updated after the trips, and the variables that need to be updated, such as travel budget and travel time, times used, are updated.

Specifically, the waiting time at the bus station is updated based on the times used by the route connected to each station. When the travel time on the route increases, the waiting time at the station also increases and vice versa. The following equation is used to update the waiting time at the station. The maximum waiting time at the station is set to be 30min, and the minimum waiting time is set to 5 minutes. Additionally, the constant 0.0002 reduces the update quantity as the travel time approaches the maximum or minimum set travel time.

Waiting Time Station = Initial waiting time station +/- (travel time * 0.0002))

The travel budget is updated at every tick with the equation.

Travel budget = Initial travel budget – the travel cost per trip

Further, if the times used exceeds the route's capacity, which is pre-set, the travel time on the routes are updated. In this equation, an exponential increment or reduction of the travel time is used with the constant 0.02. The constant here functions as explained above.

Travel time = Initial travel time - exp (times used * 0.02)

4.1.3.3. How are time modelled as discrete steps or as a continuum over which both continuous processes and discrete events can occur?

Time is represented as discrete time steps, with each tick representing a day.

4.2. Design concepts

The following design concepts guided model development. These concepts are explained by questions as already mentioned.

4.2.1. Basic principles

4.2.1.1. Which general concepts, theories, approaches are underlying the model's design?

Two significant concepts govern the model development; the Generalised Transportation Cost (GTC), the utilitarian theory (Van Wee et al., 2013). The idea that travel reduces the benefit at destinations is largely affected by the characteristics of the transport infrastructure, which entails that as the transport infrastructure changes, its influence on the utility and travel patterns will change.

4.2.1.2. Explain the relationship between these basic principles, the complexity expanded in this model, and the purpose of the study, and how were they considered?

The GTC is the aggregated cost of the monetary and non-monetary resistance required to be overcome by an individual to reach a destination. Specifically, in the model, the total GTC for the car is the summation of car travel time, car travel cost, and in-car time to station, i.e., time by car to reach the station. While for bus, the GTC is the summation of bus travel time, bus travel cost, walking time to station and waiting time at the station. On the other hand, the utilitarian theory recognises that individuals perceive travel as a disutility and that the utility is at the location of activities. Thus, agents seek to keep the utility high and the GTC as low as possible by choosing a Route that has the least total GTC.

4.2.1.3. Are they used at the level of sub-models?

The concepts are used at both the sub-model level and system level.

4.2.1.4. Will the model provide insights into the basic principles themselves, i.e., their scope, usefulness in real-world scenarios, validation, or modification (Grimm, 1999)?

The model will not provide the complexity nor expand these concepts.

4.2.1.5. Does the model use a new, or previously developed, theory for agent traits from which system dynamics emerge?

The model uses a list of agent's traits developed previously and drawn from literature in Sub-Saharan Africa. The agents' common traits have been defined from the general literature of agent's traits. Using this as guidance, in the model, only a few traits specific to Sub-Saharan Africa as found in the literature have been considered. Thus, no new agents' traits have been developed.

4.2.2. **Emergence**

4.2.2.1. What key results or outputs of the model are modelled as emerging from individuals' adaptive traits or behaviours?

Table 7 summarises the key outputs and their rationale in the model. These outcomes come as a response to the need to reach the destination while keeping GTC low. These outputs are compared among different socio-spatial classes and in changing transport environment to investigate how the model identifies travel disparities.

Table 7 Model outputs

Sn	Model output	Rationale
1	Number of bus users walking	This output measures how many bus users can sustain the use of motorised public transport in a changing transport Infrastructure, i.e., the old infrastructure, New routes and new bus stations. It is designed to understand how public transport users change their behaviour. For instance, if in the old transport the low class run out of budget does this improve in the new transport infrastructure
2	Number of car users walking	The number of bus users walking assesses the level of disparities among those in the low, middle, and high groups who change from car to walking due to being unable to sustain the use of the priority transport mode in the transport infrastructure and the segregation type.
3	Route usage by bus	This output is significant because it highlights the influence that the upgrade in the transport infrastructure can have on the travel behaviour of public transport users. The output measures the volumes by recording the number of trips made by bus from home to work.
4	Route usage by car	This output assesses the preferred routes by the car user. Thus, it shows disparities in the preferred routes between the bus users and the car users. This output is significant because it highlights the influence that the update in the transport infrastructure can have on the travel behaviour of car users.
5	Remaining mean travel budget	The output measures how much travel budget each socio-spatial economic class remains with after the change in transport infrastructure and segregation pattern(Centric, Clustered and Random). The output uses the mean travel budget of all agents in each of the three socio-spatial economic classes to assess the monetary influence of the segregation pattern and the change in the transport infrastructure.

4.2.2.2. Are there other more tightly imposed results by model rules and hence less dependent on what individuals do, and hence 'built in' rather than emergent results?

Not applicable

4.2.3. Adaptation

4.2.3.1. What adaptive traits do the individuals have?

One of the adaptive behaviours by the agents is deciding which route to use. The agents choose the route with the smallest GTC. Additionally, bus users and car users can select which route provides the least GTC. The routes also adapt to the times they are used by reducing the travel time per mode if they are not being used and increasing the travel time if they are being used more to simulate congestion.

4.2.3.2. What rules do they have for making decisions or changing behaviour in response to changes in themselves or their environment?

The agents aggregate the characteristics of the transport infrastructure. Then, if they have a sufficient travel budget, they move to the commercial patches by selecting a route with the least total impedance. However, if they run out of travel budget, the agents start walking as they are assumed to be unable to pay for the travel cost.

4.2.3.3. Do these traits explicitly seek to increase some measure of individual success regarding its objectives, Or Do they instead simply cause individuals to reproduce observed behaviours (e.g., "go uphill 70% of the time") that are implicitly assumed to convey success or fitness indirectly?

The traits and rules seek to increase the individual success of minimising the GTC to make the trip. However, each trip reduces the travel budget on a single time step, which reduces the prospects of reaching the destination if the travel budget runs out.

4.2.4. Objective

4.2.4.1. If adaptive traits explicitly act to increase some measure of the individual's success at meeting some objective, what exactly is that objective, and how is it measured?

The adaptive behaviour's objective is to minimise the GTC, resulting in a trip being made with a chosen travel mode to a predefined destination while sustaining the travel budget. This is measured through the number of trips on a route, the remaining mean travel budget and the number of car users and bus users that start walking.

4.2.4.2. When individuals make decisions by ranking alternatives, what criteria do they use?

The agents compare the utility of transport modes: private vehicle (car) and public transport (bus). The utility of travel mode is a function of the agent's attributes. In this case, the utility of mode is given by Equation 2 and equation 2 (Van Wee et al., 2013). In the model, the agents compare the GTC on a route. Impedance is defined by the sum of the waiting time at the station, travel cost per mode, travel time per mode, and travel budget. Each agent computes this value for all the possible routes to reach the destination.

$$GTC_{car} = \ Trave\ cost + travel\ time + In - car\ travel\ time$$

Equation 1 Generalised transportation cost for car

$$GTC_{bus} = Travel\ cost + travel\ time + Walking\ time\ to\ station + waiting\ time\ at\ station$$

Equation 2 Generalised transportation cost for bus

4.2.5. **Learning**

4.2.5.1. Many individuals or agents (and organisations and institutions) change their adaptive traits over time because of their experience? If so, how?

There is no learning that takes place in the model during simulation.

4.2.6. **Prediction**

4.2.6.1. suppose an agent's adaptive traits or learning procedures are based on estimating future consequences of decisions. How do agents predict the future conditions (either environmental or internal) they will experience?

Not applicable

4.2.6.2. If appropriate, what internal models are agents assumed to use to estimate future conditions or consequences of their decisions?

Not applicable

4.2.6.3. What tacit or hidden predictions are implied in these internal model assumptions?

Not applicableSensing

4.2.6.4. What internal and environmental state variables are individuals assumed to sense and consider in their decisions?

Agents sense the availability of the transport mode and impedance on the route to reach their desired destination. Additionally, agents consider how the number of trips made is depleting their travel budget.

4.2.6.5. What state variables of which other individuals and entities can an individual perceive, for example, signals that another individual may intentionally or unintentionally send?

Not applicable.

4.2.6.6. If agents sense each other through social networks, is the structure of the network imposed or emergent?

Not applicable

4.2.6.7. Are the mechanisms by which agents obtain information modelled explicitly, or are individuals simply assumed to know these variables?

Not applicable.

4.2.7. Interactions

Not applicable

4.2.8. Stochasticity

Agents' decisions are random. Additionally, during the setup of the agents' variables such as the determination of a), income in the model is a random process with income ranges between 120–3700 US dollars per month, b) the employment status, C), the socio-spatial economic class, are random and d), Due to the unknown quantities of the car ownership for the middle class, the while for the high-class everyone is assigned.

4.2.9. Collective

The collectives that exist in the model are imposed by the modeller and are represented by three socio-spatial economic classes high class, middle class, and low class.

4.2.10. Observation

The observations are conducted and collected on the data outputs shown in Table 8 from the model.

Table 8 Data collected from the model

Sn	Data collected
1	The change in the remaining mean travel budget of the agents by socio-economic status
2	The volume of route usage in the form of the number of times a route was used by car
3	The change in the number of persons with a car that starts walking
4	The change in the number of bus users that start walking
5	The volume of route usage in the form of the number of times a route was used by bus

4.3. Details

4.3.1. Initialisation

4.3.1.1. What is the initial state of the model world, i.e., at time t=0 of a simulation run?

When the setup procedure is executed, the initialisation of the model takes place. In the initialisation, the agents are created, and the breeds, i.e., persons, bus stations and links. The landscape is set up with commercial and residential patches. The residential patches are divided into three socio-spatial classes, i.e., high, middle, and low. The patches then sprout individuals and set the income between a range depending on the class range. This is followed by the initialisation of the transport infrastructure with link segments (roads), and bus stations joined by links. One bus station is located at the commercial patches, while four bus stations are situated in the residential patches to form the old transport infrastructure. The transport infrastructure is predefined by which bus stations are linked to which. The tick at this point is Zero. The waiting time, travel time, travel cost is predefined as shown in table 9, 10 and 11.

4.3.1.2. In detail, how many entities of what type are there initially, and what are the exact values of their state variables (or how were they set stochastically)?

The number of persons in the model is dependent on the number of residential patches which is 100 for each class. Thus, the total population in the model is approximately 300 agents. The income is set randomly within socio-economic classes ranging between 120 and 7300 US dollars (see Table 9, Table 10 and Table 11). The patches are divided into two types: 9 commercial patches and 300 residential patches.
Additionally, the residential patches are divided into the three socio-spatial economic classes represented by the colour blue (Low), brown (middle), and green (High). In contrast, the commercial patches are red, as seen in Figure 4. Further, for a summary of the initial values for the Road and Bus station segments as previously explained in section 4.1.3.2, see Table 10 Walking time, Travel time and Travel cost per mode for each route and Table 11.

4.3.1.3. Is initialisation always the same, or is it allowed to vary among simulations?

Initialisation varies from one simulation to the other because of the stochastic nature of the model, as explained in section 4.3.1.2.

4.3.1.4. Are the initial values chosen arbitrarily or based on data? References to those data should be provided.

The income range of the socio-spatial economic class was assumed to vary between 120-3700 US Dollars per year, while the travel cost is assumed to be between 1-3 US dollars for informal public vehicles and the summarised cost of private cars (Godard, 2013; Kumar & Barrett, 2008; Salon & Aligula, 2012; Tembe et al., 2020). See also table 2. Further, the travel times on routes for bus and car is informed by literature (Hitge & Vanderschuren, 2015). On the other, the road capacity of car and bus is chosen arbitrarily. So initial values are chosen arbitrarily, such as the constants 0.02 and 0.002 in the travel time and waiting time at station update procedure as explained in section 4.1.3.2. The population size and the scale extent are chosen arbitrarily as well. Finally, the number of stations, routes and layout are chosen arbitrarily too.

4.3.2. **Input**

4.3.2.1. Does the model use input from external sources such as data files or other models to represent processes that change over time?

Not applicable

4.3.3. **Sub-model**

4.3.3.1. What, in detail, are the sub-models that represent the processes listed in 'Process overview and scheduling?

1. Socio-spatial economic segregation
   When the model is initialised, the patches are created in two categories: residential and commercial patches.

2. Calculation of GTC
   The persons evaluate which route provides the least impedance and use it to reach the destination, as explained previously. See Equation 2 for the calculation of GTC for bus and car.

3. Choosing route
   To choose a route, the model considers the Total GTC of using a path by bus and car from any bus station. Thus, while the bus users use the station as bus stations, the car users use them as proxies to access the transport infrastructure.

4. Moving in the transport network
   When the persons have found a route with the least GTC, they move to the destination (Commercial patches) using that route in one step.

5. Number of trips on a Route
   The links are also asked to process how many times the agents use them.

6. Updating travel Budget

The persons are asked to update their travel budget immediately to move from their residential location to the central location. Each time they make a trip, the GTC reduces the travel budget relative to their mode.

7. Updating the travel time

   Each link has a variable travel time for each mode. This variable measures the time a car or bus would spend on that Route. When a route provides a lower total GTC, and persons begin to divert towards it from one with a high number of trips, the route with the high number of trips begins to reduce the GTC. At the same time, the route that becomes favourite for the persons readjust the travel time upwards.

8. Updating waiting time of station

   In the model, the stations are programmed to automatically increase or reduce their travel time depending on the times used and the travel time of their connected routes. As explained in section 4.1.3.2 with Equation 2.

4.3.3.2. What are the model parameters, their dimensions, and reference values?

The model parameters are summarised in

Table 9, while Table 10 and Table 11 for the attributes of the transport infrastructure and Table 12 show the patches' attributes.

Table 9 Population of agents in the Model

Class	Pop	Car	Bus	Income (Ann. range)	Travel Budget (% monthly income)	Empl.
Low	100	N/A	✓	0-120	15%	True
Middle	100	True/ False	✓	121-3699	25%	True
High	100	✓	True/ False	3700+	32%	True

Table 10 Walking time, Travel time and Travel cost per mode for each route

Routes	Route	Mode	Walking time to Bus station (WTB) and in-car time to station (ICT)	Capacity	Travel time (min)	Travel cost
C-D D-C	Mixed modes	Bus	WTB= (7min*Distance agent to station)/1km	20	56	1.5

		Car	ICT= (3.5min*Distance agent to station)/1km	20	51	3
C-E E-C	Mixed Modes	Bus	WTB= (7min*Distance agent to station)/1km	40	56	1.5
		Car	ICT= (3.5min*Distance agent to station)/1km	30	36	3
C-B B-C	Mixed modes	Bus	WTB= (7min*Distance agent to station)/1km	40	51	1.5
		Car	ICT= (3.5min*Distance agent to station)/1km	20	36	3
D-A A-D	Car	Car	ICT= (3.5min*Distance agent to station)/1km	40	20	3
	Bus	Bus	WTB= (7min*Distance agent to station)/1km	13	16	1.5
D-E E-D	Mixed modes	Bus	WTB= (7min*Distance agent to station)/1km	40	56	1.5
		Car	ICT= (3.5min*Dist. agent to station)/1km	30	32	3
E-B B-E		Bus	WTB= (7min*Dist. agent to station)/1km	40	54	1.5
		Car	ICT= (3.5min*Dist. agent to station)/1km	15	33	3
B-A A-B	Mixed	Bus	WTB= (7min*Dist. agent to station)/1km	40	25	1.5
		Car	ICT= (3.5min*Dist. agent to station)/1km	12	30	3
A-E E-A	Mixed	Bus	WTB= (7min*Dist. agent to station)/1km	40	54	1.5
		Car	ICT= (3.5min*Dist. agent to station)/1km	30	56	3
F-E E-F	Mixed	Bus	WTB= (7min*Dist agent to station)/1km	40	12	1.5
		Car	ICT= (3.5min*Dist to station)/1km	15	10	3

A-F F-A	Mixed	Bus	WTB= (7min*Distance agent to station)/1km	40	12.5	1.5
		Car	ICT= (3.5min*Distance agent to station)/1km	15	10	3
D-I I-D	Mixed	Bus	WTB= (7min*Distance agent to station)/1km	40	12	1.5
		Car	ICT= (3.5min*Distance agent to station)/1km	15	10	3
I-F F-I	Mixed	Bus	WTB= (7min*Distance agent to station)/1km	40	10	1
		Car	ICT= (3.5min*Distance agent to station)/1km	10	12	2.5
F- E E-F	Mixed	Bus	WTB= (7min*Distance agent to station)/1km	40	10	1.2
		Car	ICT= (3.5min*Distance agent to station)/1km	15	10	2.5
F-H H-E	Mixed	Bus	WTB= (7min*Distance agent to station)/1km	40	13	1
		Car	ICT= (3.5min*Distance agent to station)/1km	10	15	2.5
F-G G-F	Mixed	Bus	WTB= (7min*Distance agent to station)/1km	40	5	1
		Car	ICT= (3.5min*Distance agent to station)/1km	10	7	2.5
G-E E-G	Mixed	Bus	WTB=(7min*Distance agent to station)/1km	40	9	1
		Car	ICT=(3.5min*Distance agent to station)/1km	10	10	2.5
G-H H-G	Mixed	Bus	WTB=(7min*Distance agent to station)/1km	40	11	1
		Car	ICT=(3.5min*Distance agent to station)/1km	12	12	2.5
H-C C-H	Mixed	Bus	WTB=(7min*Distance agent to station)/1km	40	12	1

		Car	ICT=(3.5min*Distance agent to station)/1km	15	10	2.5
H-E E-H	Mixed	Bus	WTB=(7min*Distance agent to station)/1km	40	18	1
		Car	ICT=(3.5min*Distance agent to station)/1km	15	15	2.5
I-D D-I	Mixed	Bus	WTB=(7min*Distance agent to station)/1km	40	10	2.5
		Car	ICT=(3.5min*Distance agent to station)/1km	15	10	2.5

Table 11 Bus stations settings

Station Name	Initial Waiting time(min)
Station A	15
Station C	10
Station D	20
Station B	10
Station E	20
Station F	5
Station G	4
Station H	4
Station I	3

Table 12 The patch settings that remain constant

Patches count	Status	Land-use type	Colour
100	Low class	Residential	White
100	Middle class	Residential	Brown
100	High Class	Residential	Green
9	n/a	Commercial	Red

4.3.3.3. How were Sub-models designed or chosen, and how were they parameterized and then tested?

The sub-models were designed systematically in Netlogo. In addition, the literature review guided the conceptualisation.

5. MODEL RESULTS

This chapter presents the results from the simulations in the created Netlogo transport model. See Appendix B Model interface and Appendix C for the model code. The model was designed to investigate the travel disparities that result from the implementation of large transport infrastructure in Sub-Saharan Africa among different socio-spatial economic groups. This chapter answers the three research questions of research objective three. Firstly, the research questions aim to assess the travel behaviour of agents in an existing transport system given various levels of segregation. Secondly, to assess the travel behaviour of agents after the new transport infrastructure is introduced in the transport system. Finally, to assess travel disparities observed in agents' travel behaviour. Thus, the chapter begins by presenting the results of the baseline scenario without the new transport infrastructure. Then it presents the results of the simulations with the new transport infrastructure by first adding new routes and then adding new bus stations. Finally, these results are compared to each other to assess the travel disparities resulting from the new transport infrastructure.

5.1. Overview of emerging results from the model

The influence of the new transport infrastructure was assessed in a changing socio-spatial landscape. The model simulations presented here are from the last step of the simulation, i.e., step 30. The first section reports the results from the sensitivity analysis of the model. In the second section, a comparison is made between the old transport infrastructure influence on travel patterns and the influence of the new transport infrastructure in each segregation pattern.

5.1.1. Sensitivity Analysis

This section presents the results from the sensitivity analysis. The sensitivity analysis was run in the old transport infrastructure because the purpose of the sensitivity analysis was to assess the performance of the parameters while keeping the transport infrastructure constant. The selected statistical results presented in this section are attached to Appendix A.

The results in Appendix A show that all model parameters except for waiting time were significant for explaining route usage by bus and can account for 49.9 % of the model variation. The travel budget and travel time had the most substantial influence on the route usage by bus since most bus users are in the low- and middle-income groups and are sensitive to travel cost and travel time. This was the same case for the output route usage by cars; however, these model parameters were not as influential as in the output route usage by bus as they only accounted for 37% of the variance in the output in route usage by car.

For the remaining mean travel budget in the low, middle, and high classes, travel cost and the travel budget significantly influenced and accounted for 61%, 75.9% and 91.4% of the variance in the output, respectively. This is understandable because the remaining mean travel budget solely focused on measuring the impact of the travel cost on the travel budget. As a result, the travel cost negatively influenced the mean travel budget, while the travel budget had a positive influence.

The output that assessed the number of car users walking impacted the middle class significantly compared to the high and low classes. The travel cost and travel budget accounted for 73% of the variance in the output for the middle class, with the travel cost having a strong negative influence compared to the travel budget. The high class who have vehicles did not walk while the low class do not own private cars. Thus, this partly explains why segregation and travel budget were significant and could explain 64% of the variance in the output in the high class. Secondly, in the case of segregation, specifically for the centric pattern, the high class are located close to the commercial area; thus, they did not use the transport infrastructure; instead, they walked to the commercial area. Therefore, the model recognises the change in the number of car users using the transport infrastructure and attributes this to the segregation pattern. This is one of the indicators of the influence of segregation on travel behaviour.

The parameters that significantly influenced the output number of bus users walking in the low-class were travel cost and travel budget. Specifically, the travel budget had the strongest negative influence, and travel cost positively influenced the output. For the number of bus users walking in the high-class, the parameters segregation and travel cost had the strongest influence. Both parameters had a negative influence on the output, with segregation have a more substantial negative influence.

From this sensitivity analysis, it can be deduced that the travel cost, travel budget, and travel time were significant predictors of the outputs. Further, the sensitivity analysis highlighted that, generally, segregation was significant in influencing travel behaviour. Specifically, the Centric segregation pattern significantly influenced the high socio-spatial class, compared to Random and Clustered segregation. It was observed that segregation influences travel behaviour when segregation boundaries are defined and remain the same as spatial scales change. With further analysis, it was observed that Clustered and Random segregation are technically similar in the context of who goes to the transport infrastructure. This is because access to transport infrastructure is the same, as the clustered patches of similar groups are randomly mixed; thus, at a larger scale, it is still random segregation to some extent.

5.1.2. **Simulation results to address research objective 3**

The results in this section are addressing research objective 3. First, the section presents the results of the outputs remaining mean travel budget, the number of bus and car users that start walking, and route usage by bus and car users to investigate the travel disparities caused by a change in transport infrastructure and segregation pattern. Next, for each model output, the travel behaviour from the old transport is presented to address research question 3.1. Then to answer research questions 3.2 and 3.3, a comparison is presented for the different segregation patterns and transport infrastructure changes. This is achieved by presenting the descriptive statistics, F test results, and boxplots to compare the disparities.

5.1.2.1. Remaining mean travel budget in the old transport infrastructure

Figure 5 shows the initial and final remaining mean travel budget of agents of different classes when the transport infrastructure is kept constant and the socio-spatial segregation pattern changes. As seen in Figure 5, low-class travellers run out of the mean travel budget at the end of the simulation in all segregation patterns. In contrast, the middle class have some remaining mean travel budget. The figure further suggests that the high class still have a high mean remaining mean travel budget at the end of the simulation in all segregation patterns. Unique is the remaining mean travel budget of the clustered pattern of the high class, which shows a low median than that in the random and centric segregation yet has high variance in the data. Two key elements are clear in figure 5; firstly, the figure highlights the existing disparities among social groups that occur when new transport infrastructure is added. Secondly, in the context of travel budget, the low-class agents, which are the poor people, are the majority who are significantly affected by such a transport infrastructure.

Table 13 shows the analysis of the influence of each segregation pattern on the remaining mean travel budget. The data in table 13 highlights that segregation had no significant influence on the low, middle and high classes, as evidence by the p> .05. Thus, there was no strong evidence to reject the null hypothesis even if the F-value > 1, as the segregation pattern displayed a weak predictive capability of the remaining mean travel budget.

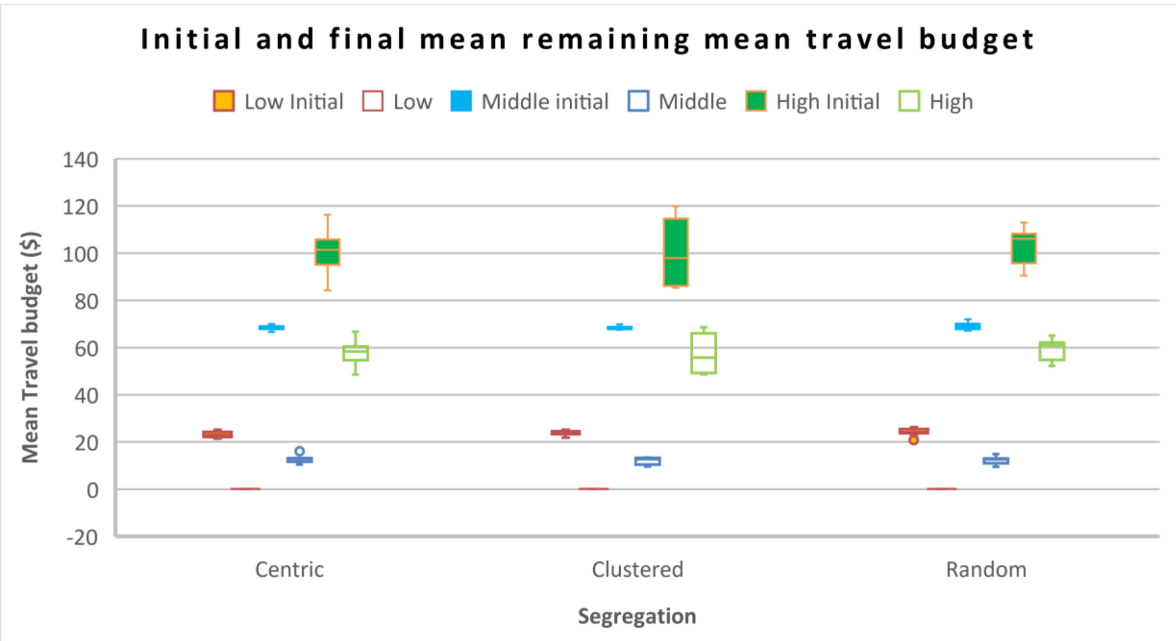

Figure 5 the mean remaining mean travel budget in old transport infrastructure in different segregation patterns

Table 13 Remaining mean, mean travel budget in old transport per segregation type and standard deviation and F-test

Mean (standard deviation) and related F-tests on remaining mean travel budget						
Class	Low		Middle		High	
Segregation	Mean (StD)	F-test	Mean (StD)	F-test	Mean (StD)	F-test
Centric	0.08 (0.03)	21.144 (df 1) P>.05	12.6 (1.5)	2.66 (df 1) p>.05	57.7(5.0)	57.25 (df 1) p >.05
Clustered	0.08 (0.04)		12.2(1.4)		58.2(7.8)	
Random	0.09 (0.03)		12.2(1.6)		58.5(4.2)	

To answer research question 3.2, the segregation pattern was kept constant; the variance in the results was significant due to the change in the transport infrastructure for the low and middle class except for the high class.

Table 14 provides the means, standard deviations, and F-statistics for the influence of the transport infrastructure. As seen in the table, the new transport infrastructure's addition seems to significantly improve the mean remaining mean travel budget of all classes for the low and middle class. However, the high class in all types of infrastructure were not influenced by the change in transport infrastructure as p>0.05, and the f value was less than one. This highlights that the mean remaining mean travel budget of the high class is not influenced when the transport infrastructure is updated.

Figure 6 presents the results of the travel disparities that existed between the old and new transport infrastructure. The comparison is between the difference in remaining mean travel budget between old and new routes and the old and news stations. As seen in figure 6, new stations produce more variation in the remaining mean travel budget leaning towards the negative values in all segregation patterns than those in the difference between the old and new routes. Further, the low class in the old and new routes do not show any difference as the boxplot is clustered around 0. For both the middle and low class in the old and new routes, the values are distributed around the 0 value, often with the boxplot quartiles shared evenly between the negative and positive values. Further, the difference between the old and new stations in the random segregation, particularly for the high class, displays a broader range and variation in the remaining mean travel budget than others.

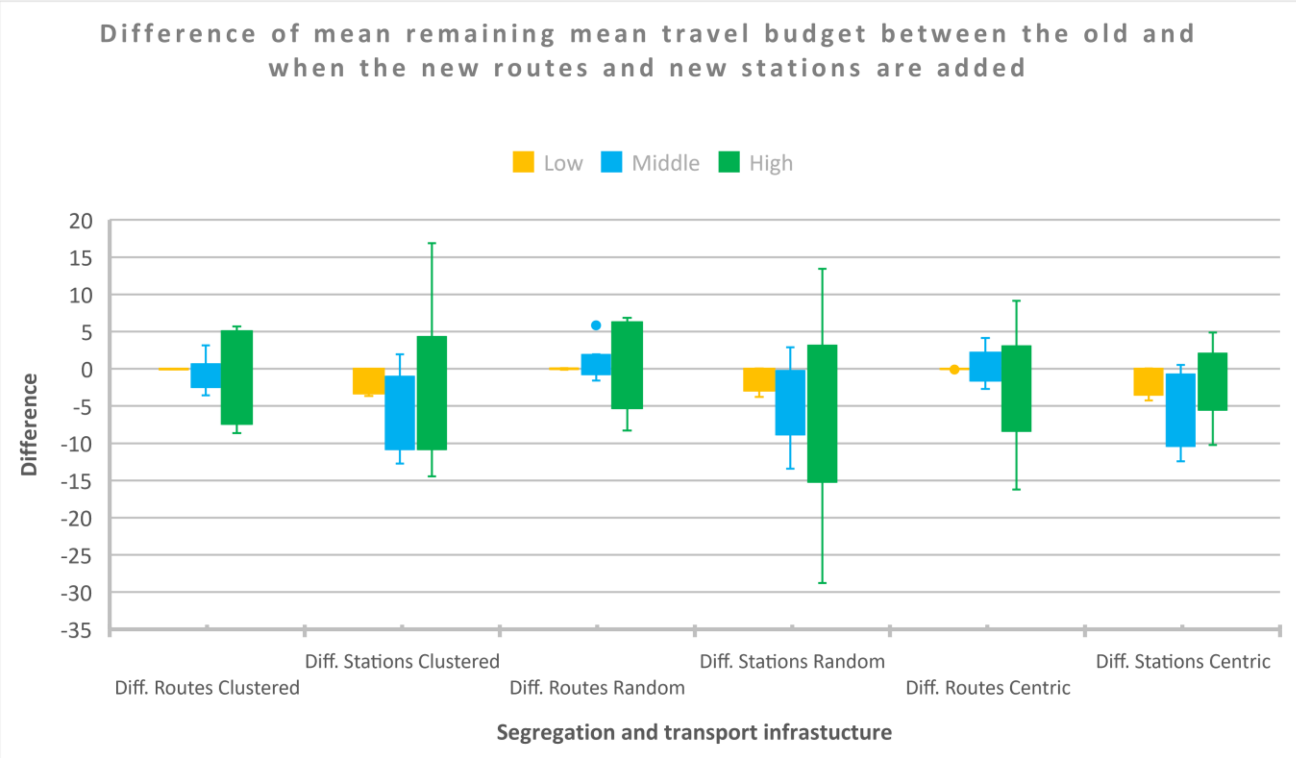

Figure 6 Comparison of the remaining mean travel budget between the old and new routes and the old and new stations transport system.

Table 14 Mean remaining mean travel budget and standard deviation in the old, new routes and stations

Centric						
	Low		Middle		High	
Infrastructure	Mean (StD)	F-test	Mean (StD)	F-test	Mean(StD)	F-test
Old	0.08(0.03)	11.587(df 1) p<.005	12.6(1.51)	10.11 (df 1) p <.005	57.68(4.96)	0.597 (df 1) p< .05
New route	0.09(0.03)		12.35(1.91)		60.91(5.39)	
New stations	1.76(1.81)		18.13(5.79)		59.37(4.08)	
Clustered						
Old	0.08(0.04)	12.189 (df 1) p <.005	12.17(1.42)	12.85 (df 1) p<.001	58.19(7.84)	0.974 (df 1) p> .05
New route	0.11(0.02)		12.66(1.16)		59.08(4.18)	
New stations	1.76(1.75)		17.93(5.7)		61.25(8.37)	
Random						
Old	0.09(0.03)	7.877 (df 1) p< .01	12.19(1.6)	8.443 (df 1) p <.01	58.5(4.35)	1.709 (df 1) p> .05
New route	0.09(0.03)		11.56(1.21)		58.16(5.58)	
New stations	1.33(1.67)		16.19(4.52)		62.51(9.57)	

5.1.2.2. Bus users walking

The section presents the results of the influence of the transport infrastructure on the travel behaviour using the number of people who changed transport mode from bus to walking while keeping segregation constant. In the context of mode choice, this output addresses the travel behaviour in new transport infrastructure. As seen in Table 15, the influence of the segregation pattern was largely on the middle class but was not significant, as seen by the p>.05. In contrast, the low class were not affected by segregation as it could not explain any variance in the data as seen by the F-value <1 and the p>.05. Figure 7 shows the disparity in the number of bus users walking between the old transport infrastructure and the new routes between the old and the new stations. As seen in Figure 7, the effect of the new routes on the number of persons walking is low compared to the new stations' effect. Further, the high class were not affected by the infrastructure change as they are not bus users. However, the low and middle classes were affected significantly by the change in infrastructure. Again, the addition of the new stations leads to a decrease in the number of bus users walking compared to adding new routes and the old infrastructure. In addition, the low class shows more variance and distribution within classes and across transport infrastructure in the clustered segregation. As seen in Table 16, the standard deviation for the old and new routes does not vary much compared to the new stations, which suggests more spread in the values of new stations.

Table 15 shows the f test for the influence of segregation on the number of bus users walking

Mean, Standard deviation and F-test for bus users walking						
	Low		Middle		High	
Segregation	Mean (StD)	F-test	(SD)	F-test	Mean(StD)	F-test
Centric	94.5(2.17)	0.243(df 1) p>.05	45.3(4.13)	1.61(df 1) p>.05	0	n/a
Clustered	92.2(2.04)		46.4(5.21)		0	
Random	94(2)		48.1(5.58)		0	

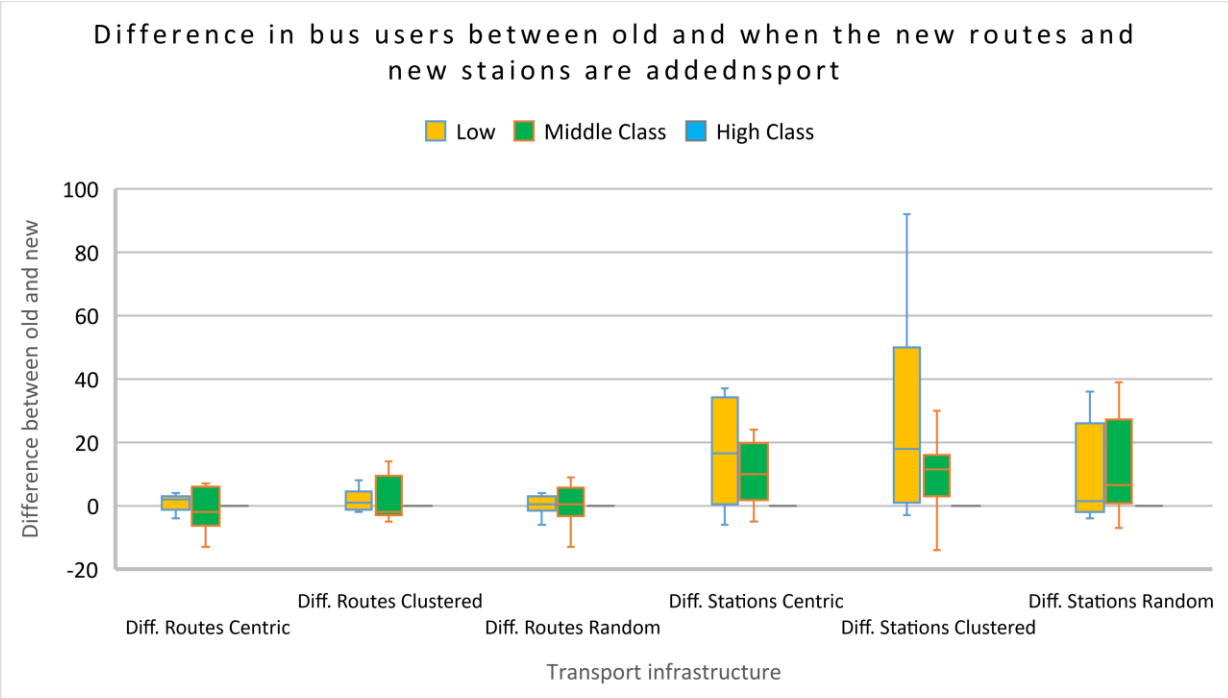

Figure 7 shows the difference between the mean bus users in old transport infrastructure and the new routes and the new stations

Table 16 F test for the mean number of bus users walking in different transportation Old, New routes and New stations while keeping the segregation constant

Centric						
Socio-class	Low		Middle		High	
	Mean (StD)	F-test	Mean (Std)	F-test	Mean (StD)	F-test
Old	94.5 (2.17)		45.3 (4.14)		0	
New route	93.5 (1.716)	12.625(df 1)	46.5 (6.28)	9.379(df 1)	0	
New Stations	77.8 (17.2)	p<.001	34.9 (9.62)	p<.005	0	0
Clustered						
Old	92.2 (2.04)		46.4 (5.21)		0	
New route	90.4 (2.591)	8.835(df 1)	43.9 (4.12)	8.923(df 1)	0	
New Stations	63.5 (36.37)	p<.005	36.9 (10.46)	p>.005	0	0
Random						
Old	94 (2)		48.1 (5.59)		0	
New route	93.8 (1.619)	6.103(df 1)	47.7 (4.52)	11.397(df	0	
New Stations	83.2 (16.45)	p<.005	36.7 (10.24)	1) p<.005	0	N/A

5.1.2.3. Car User walking

This section presents results from the output of the number of car users walking. As seen in Table 17, the segregation pattern's influence on the number of car users walking was not significant. Further, because the low-class are not car users, the results do not account for them while the high class did not change modes as such, there is not enough evidence to confirm the influence of the segregation pattern on them. Figure 8 compares the number of car users between the old and the new routes and the old and new stations. As seen in figure 8, the number of car users in the low and high-class is not affected by transport infrastructure. However, with the new routes and the stations, the difference becomes larger with more positive values and variance in the data. Further, fewer people in the middle class begin to walk with more routes and stations while the low and high classes are not accounted for. Table 18 shows that the transport infrastructure is statistically significant in influencing the number of car users walking in the middle class, as seen by the significant f value > 1. The low and high class either are not car users or were not affected and needed not to change to walking as in the case of the high class.

Table 17 shows the summary of the influence of the segregation pattern on the number of car users walking

Mean, standard deviation and the f-test						
	Low		Middle		High	
Segregation	Mean (StD)	F-test	Mean (StD)	F-test	Mean (StD)	F-test
Centric	0		45.3 (4.14)		0	
Clustered	0		46.4 (5.21)		0	
Random	0	n/a	48.1 (5.59)	1.61(df 1) p>.05	0	n/a

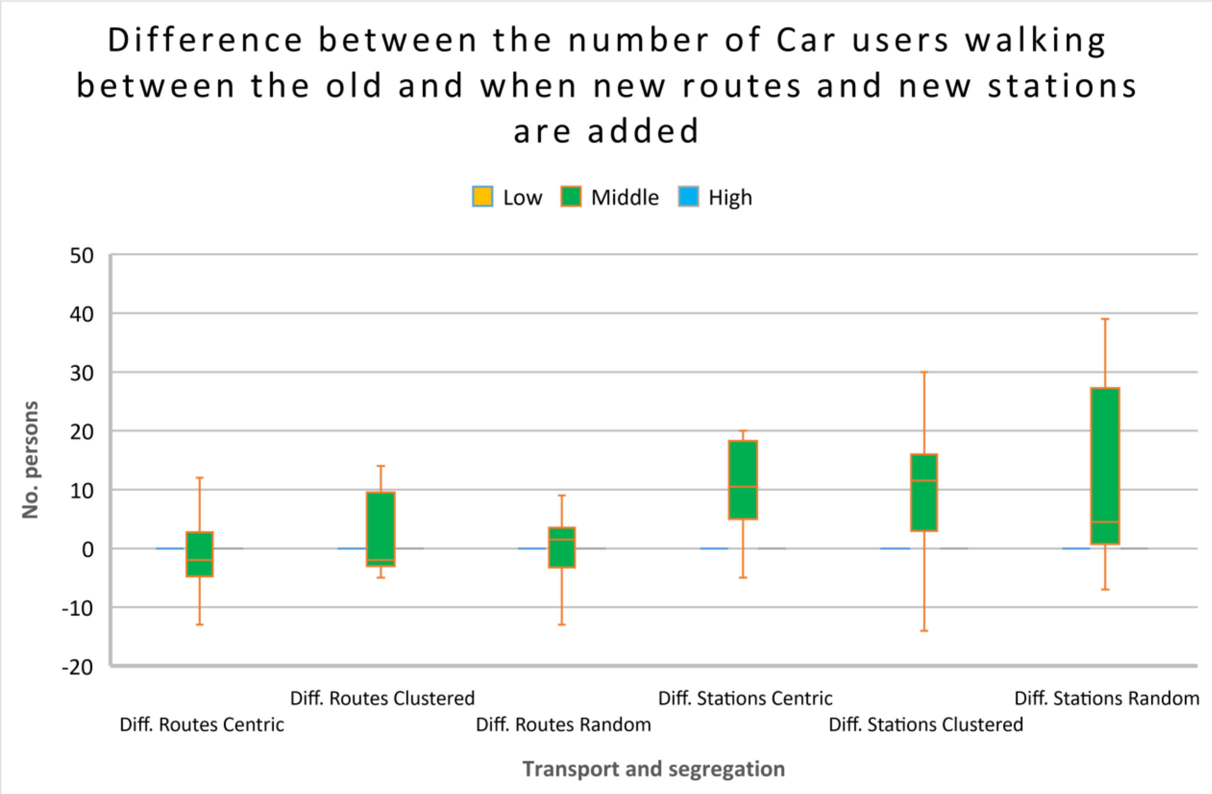

Figure 8 show the difference in the number of car users between the old and when the new routes and stations are added.

Table 18 F-test of the variation caused by a change in the transport system for car users that start walking

Centric						
Class	Low		Middle		High	
Stats	Mean (StD)	F-test	Mean (StD)	F-test	Mean (StD)	F-test
Old	0	N/A	45.30 (4.14)	7.85(df 1) p>0.005	0	N/A
New route	0		46.50 (6.28)		0	
New stations	0		34.90 (9.62)		0	
Clustered						
Old	0	N/A	46.40 (5.21)	8.923(df 1) p> .005	0	N/A
New route	0		43.90 (4.22)		0	
New stations	0		36.90 (10.46)		0	
Random						
Old	0	N/A	48.10 (5.59)	10.33(df 1) p<.005	0	N/A
New route	0		47.30 (4.52)		0	
New stations	0		37.10 (10.55)		0	

5.1.2.4. Route choice and distribution by Bus and Car users

The influence of the segregation pattern on bus and car users' route choice and usage was assessed while keeping the transport infrastructure constant. As demonstrated using route joining stations A and E and route joining stations C and E and stations DE, the segregation pattern had significant influence; however, this was largely dependent on the route's location. This can be seen in Table 19, where segregation did not influence route AE, while at the same time, Route CE was not significant but had an F-value>1 and the route DE was significantly affected by the segregation pattern.

Figures 9, 10 and 11 compare the route use of the bus users. As seen in Figure 10, travel is concentrated on two routes connecting stations D, C and E with high usage capacities of over 40. In figure 10, when the new routes are added, the concentration reduces to between 30 and 40 for the highest usage compared to the old transport infrastructure where concentration was observed. In Figure 14, when the new stations and routes are added, we observe that the highest route usage increases from 20 to 30, while most routes are between 0 and 10. This is because the additional routes absorb some usage, resulting in lower quantities on other routes.

Figure 13 and 14 show the results from the route usage by car users. It also compares the route usage in different socio-spatial patterns and the transport infrastructure. As seen in Figure 13, the route use for the centric segregation pattern is generally low, with the highest recorded use between 20 and 30 for car users. While in the clustered and random segregation pattern, the usage becomes concentrated on a single route. In the random segregation pattern, the concentration increases to two routes with higher values of route use starting to appear. This is the same scenario that we see even when the new stations are added. Thus, the centric segregation reduces the car user's route use, while the clustered and the new routes encourage the use of private vehicles.

Table 19 influence of segregation pattern on route choice and use

F tests (Centric, Clustered and Random)			
Route	df	F	Sig.
Route A E	1	0.048	0.86
Route C E	1	38.265	0.102
Route DE	1	147	0.05

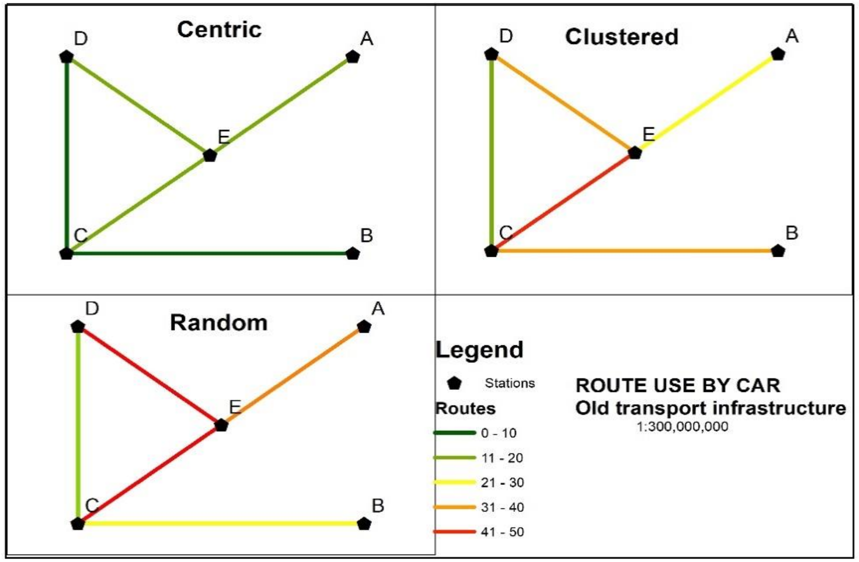

Figure 10 route use by bus in old transport

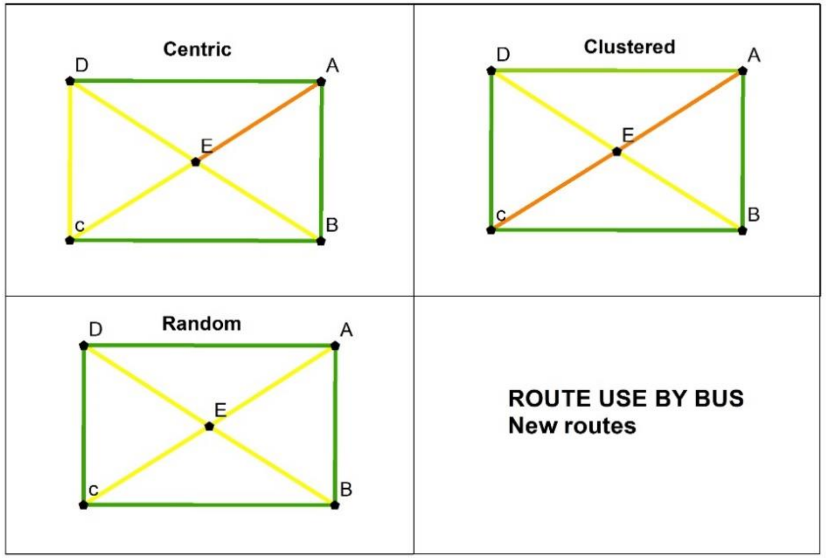

Figure 9 route use by bus in new routes

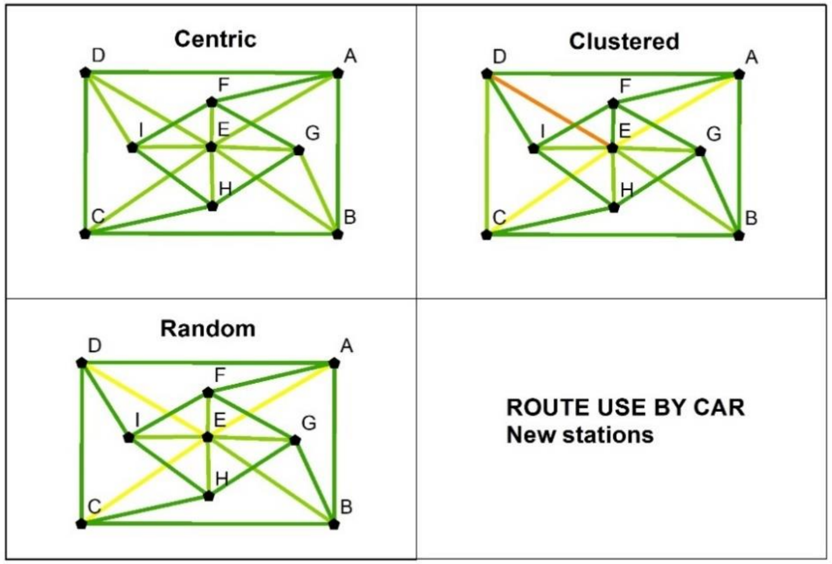

Figure 11 route use bus in new stations and routes

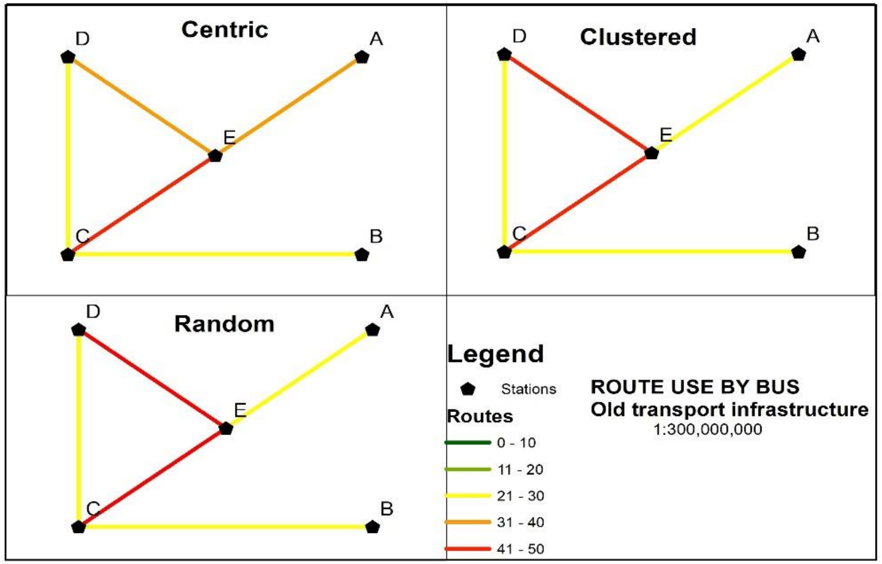

Figure 14 route use by car in old transport

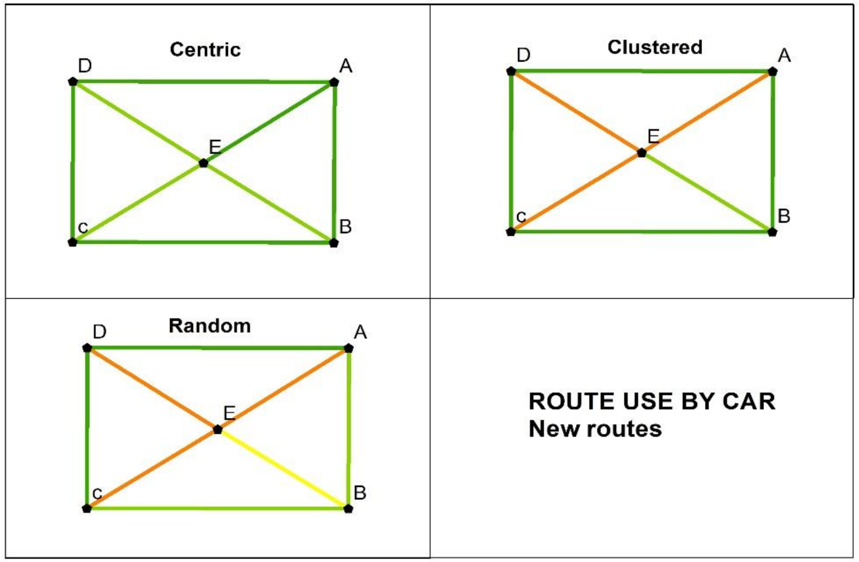

Figure 12 route use by car in new routes

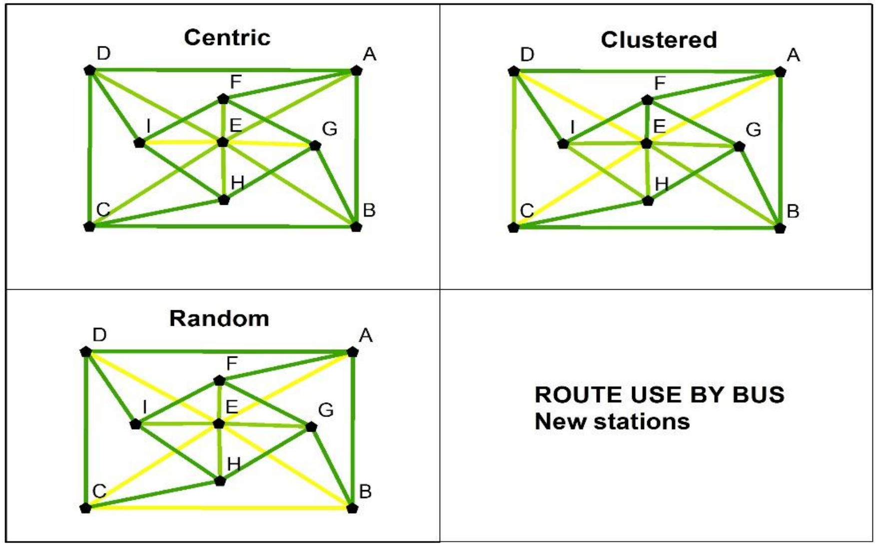

Figure 13 route use by car in new stations and new routes

5.1.3. Contextualising the results for the research questions

The research questions provided a framework on what to assess and present in the model results. This section summarises the results and key findings in the context of the research questions.

5.1.3.1. Research question 3.1

Research question 3.1 was to assess the travel behaviour in the old transport infrastructure in the various levels of segregation. Firstly, the results from the remaining mean travel budget of all agents showed that segregation did not significantly influence the remaining mean travel budget, as $p\text{-value} > 0.05$ for all segregation patterns. Secondly, the output number of car and bus users walking highlighted that segregation selectively influenced routes choice and quantity; as mentioned before, this could be attributed to the location of the starting station of the route. For instance, the centric segregation pattern reduced the number of car users, as the design of the centric segregation placed the car user close to the commercial patches where they could walk without using the transport infrastructure.

5.1.3.2. Research question 3.2

Research question two was to assess the travel behaviour in the new transport infrastructure. As seen in the results, this research question was assessed in changing a transport infrastructure while keeping the segregation pattern constant. Further, it was assessed in all the outputs of the model. The key results show that transport infrastructure had a significant impact on the travel behaviour for all outputs. However, the new routes connecting old stations to create a ring round had less impact on the travel patterns, especially for the outputs car and bus users walking and the route choice compared to the new stations.

5.1.3.3. Research question 3.3

Research question three was to assess the disparities between socio-spatial economic classes in the old and the new transport infrastructure. The means were used to compare the travel behaviours of the three socioeconomic classes in different settings to identify the travel disparities that result between the old and the new transport (new routes and new stations). First, the results showed an increase in the mean remaining mean travel budget of the low, middle, and high classes when the new stations were added. Secondly, the difference between the old and new routes, compared to the difference between the old and new stations, showed an improvement in the number of people walking in the middle and low classes. In as much as the high class were not affected by the change in transport infrastructure in the context of the remaining mean travel budget and car users walking, the results show that the low class and middle classes started benefiting from the new stations. Further, using route choice and distribution, the concentration on routes for all classes was reduced by adding the new transport infrastructure. Notably, the centric segregation reduced the number of car users while increasing transport use for the low and middle-class who were located further from the commercial patches.

6. DISCUSSION

High levels of disparity in Sub-Saharan Africa among socio-economic groups is a significant concern in transportation. The United Nations, through SDG 11, recognises the need to reduce the high levels of inequality in their various forms. However, to know what action should be taken to reduce disparities in transportation when implementing new transport infrastructure, there is a need to understand how socio-economic groups will be affected to inform decisions that are intended to reduce travel disparities. Thus, this study assessed the potential travel disparities that can result from implementing large new transport infrastructure by considering the individual socio-economic characteristics of people while acknowledging the levels of segregation.

The results indicated that changes in transport infrastructure do not affect the high classes. However, the low and middle socio-spatial economic classes were affected significantly. Finally, socio-spatial segregation has less influence on travel behaviour; however, the route choice of the high socio-economic classes was influenced more by the centric segregation pattern. Chapter 5 reported the analysis and the results from the simulation, while this chapter discusses the main findings in the broader context.

6.1. Results from the sensitivity analysis

The sensitivity analysis focused on the mean, standard deviation, minimum and maximum values of the ten simulations with the same parameters. The analysis indicated that the model results mildly varied in the spread and variation of the output values, as seen in detail in Appendix A.

The variation in the number of trips by car and bus, the remaining mean travel budget and the number of car and bus users walking could significantly be explained by the travel cost and travel budget. This could be attributed to the fact that the model design uses the monetary cost of travel as a significant influencer to the change in transport mode and the depletion of the travel budget. Additionally, segregation was influential on the high socio-spatial economic class and the route choice. Parameters such as the travel time, waiting time at the station and the travel time to the station had less significance. Specifically, the travel time to the station was not significant to these respective outputs. However, it contributed significantly to the GTC of individual agents, and the contribution can be observed when the GTC for agents leaving near stations is compared to those leaving further away from the stations.

6.2. Results from the simulations

This section discusses the result of the actual simulation in the different transport infrastructures. In addition, this section frames the discussion of the results in the broader context of the application in real-life d literature.

6.2.1. What travel behaviour exists in old transport infrastructure?

Literature suggests that factors that influence travel behaviour can be grouped into three categories: factors related to transport infrastructure, individual preferences, and the location of activities in the form of land use (Van Wee et al., 2013). These categories were informed by characteristics influencing travel behaviour in the model as highlighted by literature specific to sub-Saharan Africa. The model suggests that personal factors such as income, travel cost and car ownership are among the highest travel behaviour influencers in Sub-Saharan Africa, in line with the claim by Hitge (2015) and Kumar (2008). As identified by the UN (2015), disparities exist in different forms. Therefore, transport infrastructure and its use can be an index to the level of disparities in society caused by the difference in the socio-economic backgrounds of people. These socio-economic attributes largely influence people's travel behaviour as they determine how much of the available transport infrastructure socio-spatial economic classes can access. Further, the economic needs for transport infrastructure on the users depend on the type of infrastructure; thus, attention should be paid to the existing infrastructure and how it affects socio-economic classes to inform future transport infrastructure investment.

Maggi & Vallino (2016) highlighted that in Sub-Saharan Africa, the focus on motorised transport infrastructure prioritises the monetary cost of travel. In the model, more than 70% of agents in the lower classes ran out of the remaining mean travel budget and changed modes from car or bus to walking. These results highlighted that such a practice that focuses on the monetary aspect of travel hurt the middle and the low classes significantly compared to the high class, who are insensitive to travel costs. Thus, transport infrastructure as an economic investment (Gnade et al., 2016; Stupak, 2018), in the context of public interest and benefit, should be mingled with services that do not seek a revenue return transport provider. For instance, attention should be placed on non-motorised modes such as cycling and walking to improve the options for the lower classes. Additionally, this approach may reduce motorised travel, provide equity in travel among socio-classes, and positively impact the urban spaces by reducing pollution (Maggi & Vallino, 2016).

In the context of mode choice and change, in the model, transition to a different mode is not willingly accomplished as low and middle socio-economic people change modes because they run out of funds and are forced to seek cheaper modes. This approach in transport use is not sustainable because it does not provide a more robust basis to attract the use of non-motorised modes. It also implies that as people move to the middle and high classes, when their financial capacity increases, they will use more motorised modes, leading to other challenges like congestion, noise and air pollution (Lee, 2018).

Further, this suggests that to increase the travel budget, in addition to providing cheap infrastructure, external factors such as employment, the standard of living, and the income of the individuals might be critical elements to consider if travel disparities are to be reduced significantly. Further, the landscape design used in the model located residential and commercial areas in separate places. This practice reduces land use density and mixing, which encourages longer distances, motorised transport and is not designed around a transport system (Van Wee et al., 2013). Thus, urban planning practices that encourage transit-oriented development, mixed and dense urban land use can help reduce the spending power for the lower classes on mobility. They divert the focus from long-distance travel and motorised modes to short distances and non-motorised transport.

6.2.2. **What travel behaviour exists in New transport infrastructure?**

The model indicated an instant change in travel behaviour when the new transport infrastructure was added, as indicated in section 5.1.2. More specifically, the addition of the new stations seemed to affect the travel behaviour of the low and middle-income groups significantly than just the addition of the longer routes. The added routes and stations increase the accessibility to the infrastructure and cheaper routes. This impacts the socio-economic classes' travel budget, especially those in the low and middle classes. With the addition of the new stations, people spend less money on travel, and most agents can sustain motorised travel. Thus, affordable transport infrastructure for the lower levels of society improves their capacity to retain the travel budget and sustain motorised travel mode longer than in the old transport infrastructure. However, this depends on the infrastructure provided and the type of trip purposes it is supposed to influence. For instance, just the addition of new routes did not significantly influence the home-work related trips. The routes that joined stations that were not in the commercial areas were either not used or had very few trips made on them; as such, these routes were not significant to the home-work trips in the model. These findings were contrary to the general practice of transport provision in Sub-Saharan Africa that focuses on congestion reduction, increasing traffic flows and volumes (Meijers et al., 2012; Melser, 2020).

In the context of the remaining mean travel budget and the number of bus and car users walking, the addition of the new transport infrastructure reduced the number of bus and car users walking in the low and middle classes and improved the remaining mean travel budget. However, the model suggested that the level of travel disparity between the high and the low classes remained constant.

In the Global South, transport networks are primarily centred around motorised transport modes, which leads to significant impacts such as traffic congestion (Maggi & Vallino, 2016; Poumanyvong et al., 2012). The addition of new routes and stations reduces the overuse of the same routes. As many routes and stations become available, people have alternatives resulting in shorter travel times, distances, and reduced congestion. On the contrary, the model negates the idea of induced traffic and demand. Induced traffic and induced demand imply a condition caused by an improvement to the transport infrastructure in the context of capacity to alleviate traffic congestion, and as more traffic flows and more infrastructure exists, with time, the same congestion problems that were being solved return (Cervero, 2002; Litman, 1998). However, it can be said that induced demand is not necessarily a problem now as the transport infrastructure is still in its infancy, and land for expansion is available compared to highly urbanised areas in the Global North (Lee, 2018). On the contrary, it might not be the case for most urban Sub-Saharan cities as some have high population densities, hindering transport infrastructure expansion (United Nations, 2019). These findings suggest that every city should understand its situation and localise transport investment to work around induced traffic demand.

Further, segregation patterns such as centric segregation that place socio-economic groups in the urban spaces based on the proximity to the commercial areas largely influence travel behaviour, with the socio-spatial economic classes near the commercial patches reducing the use of the motorised transport infrastructure. However, in as much as the centric pattern reduces car users and encourages public transport, it also encourages long-distance travel for the lower classes. Thus, the benefit of the high class disadvantaged the middle and low classes as they were forced to use more of the infrastructure and risk depleting the travel budget before the end of the simulation. On the other hand, segregation patterns such as Clustered and Random resulted in concentrated travel patterns of both car and bus users. Generally, the overall quantities on the routes reduced. Thus, transport providers must understand to what degree the city is segregated and what type of segregation exists before providing transport infrastructure aimed at reducing travel disparities.

6.2.3. What disparities exist between the new and the old transport infrastructure?

This section discusses the travel disparities that were observed between the old and the new transport infrastructure. As discussed in chapter 5 model results, the disparities could be observed across socio-spatial economic classes, transport infrastructure change and segregation patterns. Across the socio-spatial segregation patterns, the low and middle classes increased their remaining mean travel budget and reduced the number of persons walking in the new transport infrastructure compared to the old transport infrastructure. Further, the High socio-spatial class were not affected significantly by the addition of the new transport infrastructure, but the travel disparities between the low, middle and high class remain the same. The Centric segregation pattern reduces car use for the high class compared to the low and middle classes, especially in the segregation pattern Centric.

Many Sub-Saharan countries focus on providing transport infrastructure that encourages motorised travel. However, to reduce travel disparities among socio-economic classes, motorised centred transport infrastructure investment may not be dependable to reduce or eliminate travel disparities. Motorised centred infrastructure improves the travel behaviour of the high class while having the same effect on the low and middle classes. Thus, the proposed transport infrastructure should be specific to what it aims to do.

Further, the multiple stations and routes seemed to significantly impact the travel pattern in the context of the car and bus users in the lower classes. Thus, the reference point in the implementation of transportation should be the lower classes of society as these are the most affected by transport change. Additionally, disparities in transport use among socio-spatial economic classes may be an enduring feature in urban transportation as other socio-economic factors external to the transport infrastructure are critical determinants of travel behaviour. Therefore, to reduce disparities in travel behaviour, elements of land use planning, individual attributes and the transport infrastructure must be carefully considered and balanced.

In countries with significant disparities, the focus for transport infrastructure investment should be the low-class people. This approach would reduce the travel disparities and improve travel for the lower classes. However, this can be a challenge as transport providers are looking for revenue returns in transport investment which is less profitable in the low classes than when the high-class are the customers (Gnade et al., 2016; Stupak, 2018). Therefore, transport investment that improves travel for the lower classes should also be attractive enough for the higher classes to balance returns and service.

6.3. Study limitations

The section highlights the limitations of the study in the model development and discussion. For example, since the model is stylised, many model parts were informed by literature. However, other necessary values such as constants for waiting time updates and in-car travel time were assumed because the information was unavailable.

Additionally, the spatial and temporal scale of the city in the model is small, with a population of 300 total agents and 30 days simulation time. Therefore, there could be challenges and discrepancies in the results when the model city is scaled up in population and size of an actual Sub-Saharan African city and the temporal scale increased.

The model was continuously checked for correctness during the model conceptualisation and development. However, due to time limitations, a thorough check of the model code was not fully completed but based on the results and how they relate to literature, the model is able to do what it was intended to do.
Furthermore, the model lacks the ability for agents to adapt and make decisions based on the status of the variables. For instance, agents should know how much travel budget they have in relation to the number of trips they have to make and change their travel behaviour based on what is remaining. Further, the model design does not allow agents to supplement their travel budget as the travel budget is set once and for all throughout the simulation. This practice in the model may not completely reflect actual life scenarios.

7. CONCLUSION

This chapter reflects the achievement of the research objectives. Further, it closes by giving scope for future study.

7.1. Reflections on the objective

The study aimed to identify potential travel disparities among socio-spatial economic classes due to the implementation of large transport infrastructure. The study developed a stylised Agent-Based Model to achieve the aim. To do this, literature reviews from sub-Saharan Africa informed the model by identifying factors that influence travel behaviour. Factors that influence travel behaviour in sub-Saharan Africa were identified. These were categorised into three classes: the factors that influence travel behaviour based on the individuals' characteristics, the transport infrastructure, and the location of activities. Factors such as travel cost and income proved to be more significant in influencing travel behaviour.

Using a stylised model aimed to imitate an entire Sub-Saharan African urban transport system and then use multiple scenarios and settings to test the impact of a change in transport infrastructure on travel behaviour. The model suggested that disparities exist among socio-spatial economic classes, and implementing new transport infrastructure can not necessarily reduce the travel disparities. Instead, it reduces the monetary cost of travel needed for agents to use the transport infrastructure in the lower and higher classes. However, transport investment should significantly improve the travel behaviour of the target class. For instance, the lower classes, which are negatively affected by a focus on motorised travel and monetary cost of travel, should be the target for transport investment that encourages easy reach to destinations.

Further, the model suggests that city form should inform what kind of transport infrastructure is required, in which areas based on the socio-spatial economic patterns. As transport providers consider transport as an economic investment where they expect returns, thus quality and quantity of transport infrastructure investment must be informed by the socio-spatial attributes of areas where it is needed. For instance, infrastructure that encourages public transportation and non-motorised modes should prioritise low car ownership areas. Additionally, to allow public travel to be competitive with private car travel, improvements should be made in how cities are designed around public transport services (Hitge & Vanderschuren, 2015; Wheeler, 2012).

Additionally, though it is beyond the scope of the objective of this study, implicitly, the model suggests that new infrastructure implementation does reduce the congestion level compared to the old transport infrastructure. However, infrastructure development should not only focus on capacity expansion to increase volumes as this is a temporal solution.

Finally, Agent-based models for transport planning and investment are a helpful support tool for decision-makers. It provides several opportunities to run simulations and multiple scenarios to provide possible outcomes of the proposed interventions informing the decision-maker. Further, in the case of limited empirical data, Agent-based modelling in transportation can act as a baseline tool for investment. However, caution must be given to the limitation of the use of the stylised models as they try to represent the real world which is far more complex than can be model. Thus, this model is intended to give a general yet reliable index of the potential impacts of new large transport infrastructure

7.2. Future work

The stylised model provides several opportunities for further study. First, particularly to the model, model validation with empirical data can be done to contextualise the model performance further and compare its performance to actual travel behaviour using a case study. This could include creating a survey tool for the collection of travel diaries at individual and household levels. Secondly, the model can incorporate machine learning capabilities. This approach would be appropriate to assess how the model can predict travel disparities up to longer periods, such as ten years or more, which the model's current state is unable to do. This would further broaden the application of the model, for instance, predicting daily or weekly travel disparities by incorporating agent behaviours in changing weather, and time of the day or months, among others.

Further, the model incorporates a limited number of parameters, with an emphasis on income and travel budget. More parameters such as safety preferences, the ability of the agents to assess the travel budget and compare it with the cost of making trips for a whole month can be included to have a representative and realistic model. Lastly, the degree to which segregation patterns influence travel behaviour can be explored as this can assist in informing planners on how city forms influence travel behaviour during the integration of city planning and transport planning.

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Appendix A Statistical results from model sensitivity and model simulations

Table A- 1 shows the variation of the results based on ten simulations for the remaining mean travel budget

The mean and standard deviation for the remaining mean travel budget												
Old												
	Low				Middle				High			
	Mean	Min	Max	Std	Mean	Mini	Max	std	Mean	Min	Max	std
Centric	0.08	0.03	0.13	0.03	12.64	10.39	16.06	1.51	57.68	48.61	66.69	4.96
Clustered	0.08	0.04	0.11	0.03	12.08	9.65	13.47	1.48	57.65	48.69	68.58	8.12
Random	0.09	0.03	0.16	0.04	12.26	9.51	14.97	1.53	58.92	52.15	65.16	4.34
New Routes												
Centric	0.09	0.05	0.13	0.03	12.35	8.77	14.93	1.91	60.91	49.91	67.21	5.39
Clustered	0.11	0.07	0.14	0.02	12.66	10.26	14.33	1.16	59.08	51.34	66.15	4.18
Random	0.09	0.05	0.15	0.03	11.56	9.13	13.30	1.21	58.16	50.08	67.19	5.58
New Stations												
Centric	1.76	0.03	4.34	1.81	18.13	11.64	26.49	5.79	59.37	55.14	66.97	4.08
Clustered	1.76	0.06	3.71	1.75	17.93	11.19	26.19	5.70	61.25	50.57	73.66	8.37
Random	1.33	0.01	3.91	1.67	16.19	11.73	22.94	4.52	62.51	49.23	80.93	9.57

Table A- 2 shows the standard deviation and mean number of car users walking

The standard deviation, minimum, maximum and the means for car users that start walking												
Old												
Status	Low				Middle				High			
Segregation	Mean	Mini	Max	Std	Mean	Min	Max	Std	Mean	Mini	Max	std
Centric	0	0	0	0	45.30	39	52	4.14	0	0	0	0
Clustered	0	0	0	0	46.00	39	56	5.21	0	0	0	0
Random	0	0	0	0	48.10	40	59	5.89	0	0	0	0
New Routes												
Centric	0	0	0	0	46.50	35	53	6.28	0	0	0	0
Clustered	0	0	0	0	43.9	39	52	4.12	0	0	0	0
Random	0	0	0	0	47.7	40	56	4.52	0	0	0	0
New Stations												
Centric	0	0	0	0	34.9	22	46	9.62	0	0	0	0
Clustered	0	0	0	0	36.9	17	53	10.46	0	0	0	0
Random	0	0	0	0	37.1	19	47	10.55	0	0	0	0

Regression results: Number of times a route is used

Table A- 3 shows the sensitivity analysis for the parameters' output number of times route C E was used.

Model Summary								
Model	R	R Square	Adjusted R Square	R Square Change	F Change	Sig. F Change	Durbin-Watson	
1	.707[a]	.500	.499	.500	718.451	.000	1.680	
ANOVA								
Model			F		Sig.			
1	Regression F test		718.451		.000[b]			
Coefficients								
Model		Unstandardized Coefficients		Standardized Coefficients	Sig.	Collinearity Statistics		
		B	Std. Error	Beta		Tolerance	VIF	
1	(Constant)	62.54	.77		.000			
	Segregation	-1.15	.25	-.04	.000	1.000	1.000	
	Waiting time	.23	.40	.005	.58	1.000	1.000	
	Travel budget	-6.55	.40	-.15	.000	1.000	1.000	
	Time to station	-1.27	.40	-.03	.002	1.000	1.000	
	Travel time	-12.09	.40	-.28	.000	1.000	1.000	
	Travel cost	2.14	.40	.05	.000	1.000	1.000	
a. Dependent Variable: times used bus of Road 1 4								

Table A- 4 Statistical summary of the times used of the route by car

Model Summary

Model	R	R Square	Adjusted R Square	R Square Change	F Change	Sig. F Change	Durbin-Watson
1	.61	.37	.371	.37	425.59	.000	.52

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	988571.96	8	123571.495	425.59	.000[b]

Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	Sig.	Collinearity Statistics	
		B	Std. Error	Beta		Tolerance	VIF
1	(Constant)	46.511	.855		.000		
	Segregation	-.350	.275	-.013	.203	1.000	1.000
	Waiting time	.158	.449	.004	.725	1.000	1.000
	Travel budget	5.833	.449	.136	.000	1.000	1.000
	Time to station	.531	.449	.012	.237	1.000	1.000
	Travel time	-5.821	.449	-.135	.000	1.000	1.000
	Travel Cost	-.998	.449	-.023	.026	1.000	1.000

a. Dependent Variable: times used car of Road 1 4

Regression Results: Mean travel budget

Table A- 5 shows the statistical results for all predictors towards the key output for measuring Mean travel budget for the middle class

Model Summary							
					Change Statistics		
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	Sig. F Change	Durbin-Watson
1	.871[a]	.759	.76	13.60	.76	.000	.65

ANOVA						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3357128.24	8	419641.03	2268.84	.000[b]

Coefficients							
		Unstandardized Coefficients		Standardized Coefficients	Sig.	Collinearity Statistics	
Model		B	Std. Error	Beta		Tolerance	VIF
1	(Constant)	10.51	.69		.000		
	Segregation	-.07	.22	-.002	.74	1.000	1.000
	Waiting Time at station	-.15	.36	-.003	.68	1.000	1.000
	Travel budget	42.04	.36	.76	.000	1.000	1.000
	Time to station	-.24	.36	-.004	.51	1.000	1.000
	Travel time	-.20	.36	-.004	.58	1.000	1.000
	Travel cost	-23.58	.36	-.43	.000	1.000	1.000
Dependent variable: Remaining mean travel budget							

Table A- 6 summary of statistical values for the parameters towards the mean travel for high class

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	Sig. F Change	Durbin-Watson
1	.956	.915	.914	12.71	.915	7698.67	.000	.90

ANOVA

Model	Regression F test	Sum of Squares	df	Mean Square	F	Sig.
1		9954313.730	8	1244289.216	7698.665	.000b

Coefficients

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	Sig.	Collinearity Statistics Tolerance	Collinearity Statistics VIF
1	(Constant)	7.460	.638		.000		
	Segregation	-.117	.205	-.002	.567	1.000	1.000
	Waiting time at station	.030	3.35	.000	.929	1.000	1.000
	Travel budget	80.913	.335	.931	.000	1.000	1.000
	Time to station	-.256	.335	-.003	.445	1.000	1.000
	Travel time	-.170	.335	-.002	.612	1.000	1.000
	Travel cost	-18.86	.335	-.217	.000	1.000	1.000

a. Dependent Variable: mean travel budget of persons with class = "high"

Table A- 7 summary of statistical values for the parameters towards the mean travel for low class

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	Sig. F Change	Durbin-Watson
1	.783	.613	.613	6.301	.613	1140.80	.000	.635

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	F test	362351.728	8	45293.966	1140.801	.000b

Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	Sig.	Collinearity Statistics	
		B	Std.Error	Beta		Tolerance	VIF
1	(Constant)	5.738	.316		.000		
	Segregation	-.022	.102	-.002	.831	1.000	1.000
	Waiting Time	.000	.166	.000	.998	1.000	1.000
	Travel budget	11.257	.166	.556	.000	1.000	1.000
	Time to station	-.122	.166	-.006	.464	1.000	1.000
	Travel time	-.046	.166	-.002	.780	1.000	1.000
	Travel Cost	-11.17	.166	-.552	.000	1.000	1.000

a. Dependent Variable: mean travel budget of persons with class = “low"

Regression: Results that measure the number car user walking

Table A- 8 shows the statistics for the predictors towards the output number of car users in the middle-class walking

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	Sig. F Change	Durbin-Watson
1	.855[a]	.731	.731	12.328	.731	1958.143	.000	.799

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	F test	2380803.847	8	297600.481	1958.143	.000[b]

Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	Sig.	Collinearity Statistics	
		B	Std. Error	Beta		Tolerance	VIF
1	(Constant)	37.838	.619		.000		
	Segregation	-.029	.199	-.001	.883	1.000	1.000
	Waiting Time	.237	.325	.005	.466	1.000	1.000
	Travel budget	-13.076	.325	-.275	.000	1.000	1.000
	Time to station	.167	.325	.004	.606	1.000	1.000
	Travel time	.254	.325	.005	.434	1.000	1.000
	Travel cost	10.857	.325	.228	.000	1.000	1.000

a. Dependent Variable: count persons with class = "middle" and car = true and mytravel-budget = 0

Table A- 9 Summary of statistics for the predictors toward the output number of people walking that have car in the high class

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	Sig. F Change	Durbin-Watson
1	.802[a]	.644	.643	13.075	.644	1298.385	.000	1.025

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression f-test	1775729.782	8	221966.223	1298.385	.000[b]

Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	Sig.	Collinearity Statistics	
		B	Std. Error	Beta		Tolerance	VIF
1	(Constant)	88.53	.656		.000		
	Segregation	-.828	.211	-.031	.000	1.000	1.000
	Waiting time at station	-.048	.345	-.001	.889	1.000	1.000
	Travel budget	-24.89	.345	-.569	.000	1.000	1.000
	Time to station	.015	.345	.000	.965	1.000	1.000
	Travel time	.072	.345	.002	.834	1.000	1.000
	Travel cost	-.009	.345	.000	.979	1.000	1.000

a. Dependent Variable: count persons with class = "high" and car = true and mytravel-budget = 0

Regression: Count of persons with bus users walking

Table A- 10 Summary of statistics for the predictors toward the output number of bis users in the low-class walking

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	Sig. F Change	Durbin-Watson
1	.803[a]	.645	.645	24.721	.645	1307.023	.000	.633

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	6389965.806	8	798745.726	1307.023	.000[b]

Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	Sig.	Collinearity Statistics	
		B	Std. Error	Beta		Tolerance	VIF
1	(Constant)	77.66	1.240		.000		
	Segregation	-.210	.399	-.004	.598	1.000	1.000
	Waiting time at station	.049	.651	.001	.940	1.000	1.000
	Travel budget	-50.04	.651	-.603	.000	1.000	1.000
	Time to station	.454	.651	.005	.486	1.000	1.000
	Travel time	.240	.651	.003	.712	1.000	1.000
	Travel cost	43.97	.651	.530	.000	1.000	1.000

a. Dependent Variable: count persons with class = "low " and bus = true and mytravel-budget = 0

Table A- 11 Summary of statistical results for the number of bus users walking

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	Sig. F Change	Durbin-Watson
1	.990[a]	.980	.980	3.526	.980	35478.475	.000	1.943

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3528497.572	8	441062.197	35478.475	.000[b]
	Residual	71495.427	5751	12.432		
	Total	3599992.999	5759			

Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	Sig.	Collinearity Statistics	
		B	Std. Error	Beta		Tolerance	VIF
1	(Constant)	49.907	.177		.000		
	Segregation	-.197	.057	-.006	.001	1.000	1.000
	Waiting time at stations	.018	.093	.000	.846	1.000	1.000
	Travel budget	-49.499	.093	-.990	.000	1.000	1.000
	Time to station	.093	.093	.002	.317	1.000	1.000
	Travel time	-.163	.093	-.003	.079	1.000	1.000
	Travel cost	-.010	.093	.000	.917	1.000	1.000

a. Dependent Variable: count persons with class = "high" and bus = true and mytravel-budget = 0

Appendix B Model interface

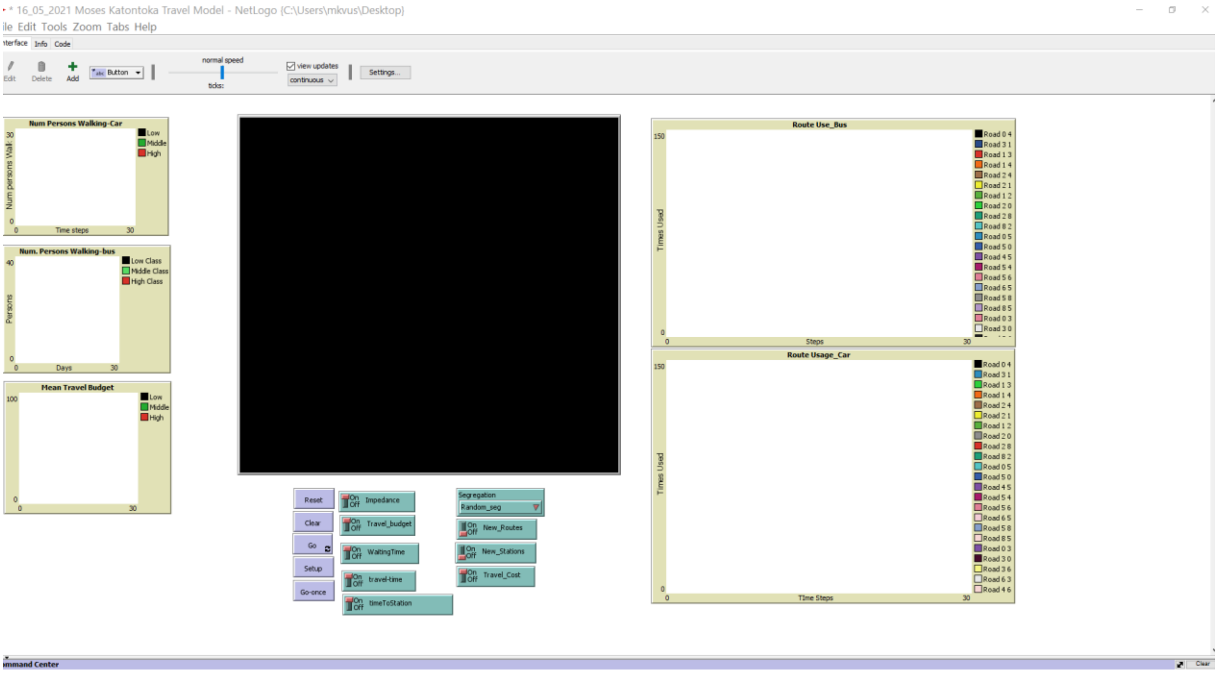

Figure A- 1 the model interface in Netlogo

Appendix C Model code

```
patches-own        [commercial residential status]
links-own           [ TotalImpedance traveltimebus traveltimecar capacityca capacitybus timesusedbus
                    timesusedcar timesused car-travel-cost bus-travel-cost]
breed               [persons person]
breed               [bstations bstation]
bstations-own     [stationName WaitingTimeStation ]
persons-own       [mode car income mytravel-budget travel-budget bus class myhome mydistance
                  walkingtimeStation incartime starting_station alive]
Extensions          [Nw]
Globals             [ ]
Directed-link-breed   [Roads Road]
to Erase
  clear-all
end
to setup
  clear-all
  if Segregation = "Random_seg" [
    ask patch 0 0 [ set pcolor red ask neighbors [ set pcolor red]]
    ask n-of 100 patches with [pcolor != red] [set pcolor brown]
    ask n-of 100 patches with [pcolor != brown and Pcolor != Red][set pcolor green ]
    ask n-of 100 patches with [pcolor != brown and pcolor != red and Pcolor != green ][set pcolor white ]
  ]
  if Segregation = "Centric"
  [
    ask patch 0 0 [ set pcolor red ask neighbors
      [ set pcolor red] ]
    ask patch 0 0 [ ask n-of 100 patches in-radius 7 with
      [pcolor != red][set pcolor green] ]
    ask patch 0 0 [ask n-of 100 patches in-radius 12 with
      [pcolor != red and pcolor != green]
      [set pcolor brown ] ]
    ask patch 0 0 [ask n-of 100 patches in-radius 16 with [pcolor != brown and pcolor != red and pcolor !=
green]
      [set pcolor white]] ]
```

```
if Segregation = "Stationbased"
[ ask patch 0 0 [ set pcolor red ask neighbors [set pcolor red ]]
  ask patch 10 10 [ ask n-of 50 patches in-radius 5 [ set pcolor white]]
  ask patch 10 -10 [ ask n-of 50 patches in-radius 5 [set pcolor white]]
  ask patch -10 10 [ ask n-of 100 patches in-radius 6 [ set pcolor brown]]
  ask patch -10 -10 [ ask n-of 100 patches in-radius 6 [ set pcolor green]  ]
if Segregation = "Clustered"
[    ask patch 0 0 [ set pcolor red ask neighbors [set pcolor red ]]
  ask n-of 26 patches [set pcolor green]
  while [count patches with [pcolor = green] <= 100]
  [ask one-of patches with [pcolor = green] [
    let tempneighbor one-of neighbors4 with [pcolor != red and pcolor != green]
    if tempneighbor != nobody [ ask tempneighbor [set pcolor green]     ]    ]   ]
  ask n-of 16 patches [set pcolor brown]
  while [count patches with [pcolor = brown] <= 100]
  [ask one-of patches with [pcolor = brown] [
    let tempneighbor one-of neighbors4 with [pcolor != green and pcolor != red and pcolor != brown]
    if tempneighbor != nobody [ ask tempneighbor [set pcolor brown]
    ] ]]
  ask n-of 20 patches [set pcolor white]
  while [count patches with [pcolor = white] < 100] [
   ask one-of patches with [pcolor = white] [
    let tempneighbor one-of neighbors4 with [pcolor != green and pcolor != brown and pcolor != red]
    if tempneighbor != nobody [ ask tempneighbor [set pcolor white]]]]  ]
ask patches with [pcolor = green ] [ set residential true set status "high"]
ask patches with [pcolor = brown ] [ set residential true set status "middle" ]
ask patches with [pcolor = white ] [ set residential true set status "low"]
setup-bstations-network
ask patches with [pcolor = green]
[    sprout-persons 1    [
    set shape "person" set class "high" set car true set bus one-of [true false] set income one-of ( range 7300
8000)
    if Travel_budget = true [set travel-budget ((income  / 12) * 0.32)] ] ]
ask patches with [pcolor = white]
[  sprout-persons 1
```

```
  [    set shape "person" set class "middle" set bus true set car one-of [true false] set income one-of (range 3700 7299 ) if Travel_Budget = true [set travel-budget ((income  / 12) * 0.15)] ]  ]
 ask patches with [pcolor = brown]
  [    sprout-persons 1    [      set shape "person" set class "low " set bus true  set income one-of (range 120 3699)
      if Travel_budget = true [set travel-budget ((income  / 12) * 0.15)]    ]  ]
  ask persons [    set color black set myhome patch-here]
  ask persons [set alive true]   ask persons with [ alive = true][set mydistance distance min-one-of bstations[distance myself]]  set-walking-time-station-and-in-car-time
    reset-ticks
end
to setup-bstations-network
  create-bstations 1 [ setxy 10 10  set shape "box" set size 2  set label "Station 0" set WaitingTimeStation 15]
  create-bstations 1 [ setxy -10 -10 set shape "box" set size 2  set label "Station 1" set WaitingTimeStation 10]
  create-bstations 1 [ setxy -10 10 set shape "box" set size 2  set label "Station 2" set WaitingTimeStation 20]
  create-bstations 1 [ setxy 10 -10 set shape "box" set size 2  set label "Station 3" set WaitingTimeStation 10]
  create-bstations 1 [ setxy 0 0 set shape "box" set size 2  set label "CENTRAL STATION"
    set WaitingTimeStation 20]
  create-links
end
to create-links
  ask one-of bstations with [label = "CENTRAL STATION"]
  [ create-Road-from one-of other bstations with [ label = "Station 1"]
    ask road 1 4 [set shape "roads" set traveltimebus 56 set traveltimecar 36  set capacitycar 30 set capacitybus 40 set car-travel-cost  3 set bus-travel-cost 1.5 ]]
  ask one-of bstations with [label = "CENTRAL STATION"]
  [ create-Road-to one-of other bstations with[ label = "Station 1"]
    ask road  4 1 [
      set shape "roads" set traveltimebus 56 set traveltimecar 36
      set capacitycar 30 set capacitybus 40 if Travel_Cost = true [set car-travel-cost 3 set bus-travel-cost 1.5]]]
  ask bstations with [label = "CENTRAL STATION"]
  [create-Road-from one-of other bstations with [ label = "Station 2"]
    ask road 2 4 [set shape "roads" set traveltimebus 56 set traveltimecar 32
      set capacitycar 30 set capacitybus 40  if Travel_Cost = true [set car-travel-cost 3 set bus-travel-cost 1.5]]]
  ask bstations with [label = "CENTRAL STATION"]
```

```
  [create-Road-to one-of other bstations with [ label = "Station 2"]
    ask road 4 2 [set shape "roads"  set traveltimebus 56 set traveltimecar 32
      set capacitycar 30 set capacitybus 40 if Travel_Cost = true [set car-travel-cost 3 set bus-travel-cost 1.5]]]
  ask bstations with [label = "CENTRAL STATION"]  [create-Road-from one-of other bstations with [ label
= "Station 0"]
    ask Road 0 4 [set shape "roads"
      set traveltimebus 54  set traveltimecar 56      set capacitycar 30 set capacitybus 40
       if Travel_Cost = true [set car-travel-cost 3 set bus-travel-cost 1.5]]]
  ask bstations with [label = "CENTRAL STATION"]
  [create-Road-to one-of other bstations with [ label = "Station 0"]
    ask Road 4 0 [set shape "roads" set traveltimebus 54
      set traveltimecar 56 set capacitycar 30 set capacitybus 40
       if Travel_Cost = true [set car-travel-cost 3 set bus-travel-cost 1.5]]]
  ask bstations with [label = "Station 3"]
  [create-Road-from one-of other bstations with [ label = "Station 1"]
    ask Road 1 3 [set shape "roads"
      set traveltimebus 51  set traveltimecar 36
      set capacitycar 20 set capacitybus 40
       if Travel_Cost = true [set car-travel-cost 3 set bus-travel-cost 1.5]]]
  ask bstations with [label = "Station 3"]
  [create-Road-to one-of other bstations with [ label = "Station 1"]
    ask Road 3 1 [set shape "roads"
      set traveltimebus 51  set traveltimecar 36
      set capacitycar 20 set capacitybus 40
       if Travel_Cost = true[set car-travel-cost 3 set bus-travel-cost 1.5 ]]]
  ask bstations with [label = "Station 1"]
  [create-Road-from one-of other bstations with [ label = "Station 2"]
    ask Road 2 1 [set shape "roads"
      set traveltimebus 30  set traveltimecar 15
      set capacitycar 20 set capacitybus 40
       if Travel_Cost = true [set car-travel-cost 3 set bus-travel-cost 1.5]]]
  ask bstations with [label = "Station 1"]
  [create-Road-to one-of other bstations with [ label = "Station 2"]
    ask Road 1 2 [set shape "roads"
      set traveltimebus 30  set traveltimecar 15
      set capacitycar 20 set capacitybus 40
```

```
      if Travel_Cost = true[set car-travel-cost 3  set bus-travel-cost 1.5]]]
  if New_Stations[ create-bstations 1 [ setxy 0 6 set shape "box" set size 2 set label "New_Station1" set WaitingTimeStation 5]]
  if New_Stations [ create-bstations 1[setxy 6 0  set shape "Box" set size 2 set label "New_Station2" set WaitingTimeStation 4]]
  if New_Stations[ create-bstations 1 [ setxy 0 -6 set shape "box" set size 2 set label "New_Station3" set WaitingTimeStation 4]]
  if New_Stations [ create-bstations 1[setxy -6 0 set shape "Box" set size 2 set label "New_Station4" set WaitingTimeStation 3]]
  if New_Stations [  ask bstations with [ label = "New_Station2"] [create-Road-to one-of other bstations with [ Label = "CENTRAL STATION" ]
    ask Road 6 4 [ set shape "roads"
      set traveltimebus 9 set traveltimecar 10
      set capacitycar 10  set capacitybus 40
      if Travel_Cost = true[set car-travel-cost 2.5 set bus-travel-cost 1]]]]
  if New_Stations [  ask bstations with [ label = "New_Station2"] [create-Road-from one-of other bstations with [ Label = "CENTRAL STATION" ]
    ask Road 4 6 [ set shape "roads"
      set traveltimebus 9 set traveltimecar 10
      set capacitycar 10 set capacitybus 40
      if Travel_Cost = true[set car-travel-cost 2.5 set bus-travel-cost 1]]]]
  if New_Stations [  ask bstations with [ label = "New_Station2"] [create-Road-to one-of other bstations with [ Label = "New_Station3"]
    ask Road 6 7 [ set shape "roads"
      set traveltimebus 11
      set traveltimecar 12
      set capacitycar 12 set capacitybus 40
      if Travel_Cost = true[set car-travel-cost 2.5 set bus-travel-cost 1 ]]]]
  if New_Stations [  ask bstations with [ label = "New_Station2"] [create-Road-from one-of other bstations with [ Label = "New_Station3" ]
    ask Road 7 6 [ set shape "roads"
      set traveltimebus 11 set traveltimecar 12
      set capacitycar 12 set capacitybus 40
      if Travel_Cost = true[set car-travel-cost 2.5 set bus-travel-cost 1]]]]
  if New_Stations [  ask bstations with [ label = "New_Station3"] [create-Road-to one-of other bstations with [ Label = "CENTRAL STATION" ]
```

```
    ask Road 7 4 [ set shape "roads"
      set traveltimebus 18 set traveltimecar 15
      set capacitycar 15 set capacitybus 40
      if Travel_Cost = true[set car-travel-cost 2.5 set bus-travel-cost 1]]]]
  if New_Stations [  ask bstations with [ label = "New_Station3"] [create-Road-from one-of other bstations
with [ Label = "CENTRAL STATION" ]
    ask Road 4 7 [ set shape "roads"
      set traveltimebus 18 set traveltimecar 15
      set capacitycar 15 set capacitybus 40
      if Travel_Cost = true[set car-travel-cost 2.5 set bus-travel-cost 1]]]]
  if New_Stations [ ask bstations with [ label = "New_Station1"] [create-Road-to one-of other bstations with
[ Label = "New_Station2"]
    ask Road 5 6 [ set shape "roads"
      set traveltimebus 5 set traveltimecar 7
      set capacitycar 10 set capacitybus 40
      if Travel_Cost = true[set car-travel-cost 2.5 set bus-travel-cost 1 ]]]]
  if New_Stations [  ask bstations with [ label = "New_Station1"] [create-Road-from one-of other bstations
with [ Label = "New_Station2" ]
    ask Road 6 5 [ set shape "roads"
      set traveltimebus 5 set traveltimecar 7
      set capacitycar 10 set capacitybus 40
      if Travel_Cost = true[set car-travel-cost 2.5 set bus-travel-cost 1]]]]
  if New_Stations [ ask bstations with [ label = "New_Station4"] [create-Road-to one-of other bstations with
[ Label = "New_Station1"]
    ask Road 8 5 [ set shape "roads"
      set traveltimebus 10 set traveltimecar 12
      set capacitycar 10 set capacitybus 40
      if Travel_Cost = true [set car-travel-cost 2.5 set bus-travel-cost 1]]]]
  if New_Stations [  ask bstations with [ label = "New_Station4"] [create-Road-from one-of other bstations
with [ Label = "New_Station1" ]
    ask Road 5 8 [ set shape "roads"
      set traveltimebus 10 set traveltimecar 12
      set capacitycar 10 set capacitybus 40
      if Travel_Cost = true[set car-travel-cost 2.5 set bus-travel-cost 1]]]]
```

```
if New_Stations [ ask bstations with [ label = "New_Station4"] [create-Road-to one-of other bstations with [ Label = "New_Station3"]
   ask Road 8 7 [ set shape "roads"
     set traveltimebus 13 set traveltimecar 15
     set capacitycar 10 set capacitybus 40
     if Travel_Cost = true[set car-travel-cost 2.5 set bus-travel-cost 1]]]]
if New_Stations [  ask bstations with [ label = "New_Station4"] [create-Road-from one-of other bstations with [ Label = "New_Station3" ]
   ask Road 7 8 [ set shape "roads"
     set traveltimebus 13 set traveltimecar 15
     set capacitycar 10 set capacitybus 40
     if Travel_Cost = true[set car-travel-cost 2.5 set bus-travel-cost 1]]]]
if New_Stations [ ask bstations with [ label = "New_Station2"] [create-Road-to one-of other bstations with [ Label = "Station 3"]
   ask Road 6 3  [ set shape "roads"
     set traveltimebus 11 set traveltimecar 12
     set capacitycar 10 set capacitybus 40
     if Travel_Cost = true [set car-travel-cost 2.5 set bus-travel-cost 1]]]]
if New_Stations [  ask bstations with [ label = "New_Station2"] [create-Road-from one-of other bstations with [ Label = "Station 3" ]
   ask Road 3 6 [ set shape "roads"
     set traveltimebus 11 set traveltimecar 12
     set capacitycar 10 set capacitybus 40
     if Travel_Cost = true[set car-travel-cost 2.5 set bus-travel-cost 1]]]]
if New_Stations [ ask bstations with [ label = "New_Station3"] [create-Road-to one-of other bstations with [ Label = "Station 1"]
   ask Road 7 1 [ set shape "roads"
     set traveltimebus 12 set traveltimecar 10
     set capacitycar 15 set capacitybus 40
     if Travel_Cost = true[set car-travel-cost 2.5 set bus-travel-cost 1]]]]
if New_Stations [  ask bstations with [ label = "New_Station3"] [create-Road-from one-of other bstations with [ Label = "Station 1" ]
   ask Road 1 7 [ set shape "roads"
     set traveltimebus 12 set traveltimecar 10
     set capacitycar 15 set capacitybus 40
     if Travel_Cost = true[set car-travel-cost 2.5 set bus-travel-cost 1]]]]
```

```
  if New_Stations [ask bstations with [ label = "New_Station4"] [create-Road-to one-of other bstations with
[Label = "Station 2"]
    ask Road 8 2 [ set shape "roads"
      set traveltimebus 12 set traveltimecar 10
      set capacitycar 15 set capacitybus 40
      if Travel_Cost = true [set car-travel-cost 2.5 set bus-travel-cost 2.5]]]]
  if New_Stations [ask bstations with [ label = "New_Station4"] [create-Road-from one-of other bstations
with [Label = "Station 2"]
    ask Road 2 8 [ set shape "roads"
      set traveltimebus 12 set traveltimecar 10
      set capacitycar 15 set capacitybus 40
      if Travel_Cost = true[set car-travel-cost 2.5 set bus-travel-cost 2.5]]]]
  if New_Stations [ask bstations with [ label = "New_Station4"] [create-Road-to one-of other bstations with
[Label = "CENTRAL STATION"]
    ask Road 8 4 [ set shape "roads"
      set traveltimebus 10 set traveltimecar 10
      set capacitycar 15 set capacitybus 40
      if Travel_Cost = true[set car-travel-cost 2.5 set bus-travel-cost 1.2]]]]
  if New_Stations [ask bstations with [ label = "New_Station4"] [create-Road-from one-of other bstations
with [Label = "CENTRAL STATION"]
    ask Road 4 8 [ set shape "roads"
      set traveltimebus 10 set traveltimecar 10
      set capacitycar 15 set capacitybus 40
      if Travel_Cost = true[set car-travel-cost 2.5 set bus-travel-cost 1.2]]]]
  if New_Routes [  ask bstations with [ label = "New_Station1"] [create-Road-to one-of other bstations with
[ Label = "CENTRAL STATION" ]
    ask Road 5 4 [ set shape "roads"
      set traveltimebus 12 set traveltimecar 10
      set capacitycar 15  set capacitybus 40
      if Travel_Cost = true[set car-travel-cost 3 set bus-travel-cost 1.5]]]]
  if New_Routes [  ask bstations with [ label = "New_Station1"] [create-Road-from one-of other bstations
with [ Label = "CENTRAL STATION" ]
    ask Road 4 5 [ set shape "roads"
      set traveltimebus 12 set traveltimecar 10
      set capacitycar 15 set capacitybus 40
```

```
    if Travel_Cost = true[set car-travel-cost 3 set bus-travel-cost 1.5]]]]
  if New_Routes [ask bstations with [ label = "New_Station1"] [create-Road-to one-of other bstations  with [ label = "Station 0"]
   ask Road 5 0 [ set shape "roads"
    set traveltimebus 12.5 set traveltimecar 10
    set capacitycar 15 set capacitybus 40
    if Travel_Cost = true[ set car-travel-cost 3 set bus-travel-cost 1.5]]]]
  if New_Routes [ask bstations with [ label = "New_Station1"] [create-Road-from one-of other bstations with [ label = "Station 0"]
   ask Road 0 5 [ set shape "roads"
    set traveltimebus 12.5 set traveltimecar 10
    set capacitycar 15 set capacitybus 40
    if Travel_Cost = true[set car-travel-cost 3 set bus-travel-cost 1.5]]]]
  if New_Routes [ask bstations with [ label = "Station 0"] [create-Road-to one-of other bstations with [label = "Station 3"]
   ask Road 0 3  [set shape "roads"
    set traveltimebus 25 set traveltimecar  30
    set capacitycar 12 set capacitybus 40
    if Travel_Cost = true [set car-travel-cost 3 set bus-travel-cost 1.5]]]]
  if New_Routes [ask bstations with [ label = "Station 0"] [create-Road-from one-of other bstations with [label = "Station 3"]
   ask Road 3 0 [set shape "roads"
    set traveltimebus 25 set traveltimecar 30
    set capacitycar 12 set capacitybus 40
    if Travel_Cost = true[set car-travel-cost 3 set bus-travel-cost 1.5]]]]
  if New_Routes [ask bstations with [ label = "Station 0"] [create-Road-to one-of other bstations with [label = "Station 2"]
   ask Road 0 2 [set shape "roads"
    set traveltimebus 16 set traveltimebus 12
    set capacitycar 13 set capacitybus 40
    if Travel_Cost = true[set car-travel-cost 3 set bus-travel-cost 1.5]]]]
  if New_Routes [ask bstations with [ label = "Station 0"] [create-Road-from one-of other bstations with [label = "Station 2"]
   ask Road 2 0 [set shape "roads"
    set traveltimebus 16 set traveltimebus 12
    set capacitycar 13 set capacitybus 40
```

```
      if Travel_Cost = true[set car-travel-cost 3 set bus-travel-cost 1.5]]]]
  if New_Routes [ask bstations with [ label = "Station 3"][ create-Road-to one-of other bstations with [label
= "CENTRAL STATION"]
    ask Road 3 4 [set shape "roads"
      set traveltimebus 54 set traveltimecar 33
      set capacitycar 15 set capacitybus 40
      if Travel_Cost = true[set car-travel-cost 3 set bus-travel-cost 1.5]]]]
  if New_Routes [ask bstations with [ label = "Station 3"][ create-Road-from one-of other bstations with
[label = "CENTRAL STATION"]
    ask Road 4 3 [set shape "roads"
      set traveltimebus 54 set traveltimecar 33
      set capacitycar 15 set capacitybus 40
      if Travel_Cost = true[set car-travel-cost 3 set bus-travel-cost 1.5]]]]
end
to Go
  ask links [ set timesusedbus 0 set timesusedcar 0]
  Move-transport-agents
   update_travel_time
  update_waiting_time
  if ticks = 30 [stop]
  tick
  end
to Move-transport-agents

  ask persons with [alive = true]  [
    move-to min-one-of bstations [distance myself]
    let starting [label] of bstations-here
    set starting_station starting      ]
  ask persons with [ alive = true and count bstations-here with [ label != "CENTRAL STAIION"] > 0 ]  [
    let currentstation bstations-here
        let destination one-of bstations with [label = "CENTRAL STATION"]
    let myCar Car
    let mybus bus
    let myIncarTime incartime
    let mywalkingtimeStation walkingtimeStation
    let temproute nobody
```

```
  ask currentstation [
    ask my-out-Roads [calculateMyImpedance myCar mybus currentstation myIncarTime mywalkingtimeStation
      let mybus-travel-cost bus-travel-cost
      let mycar-travel-cost car-travel-cost
      ask persons [if bus = true [set mytravel-budget (travel-budget - mybus-travel-cost * ticks) if mytravel-budget < 0 [set mytravel-budget 0]]
        if car = true and bus = true [ set mytravel-budget (travel-budget - mycar-travel-cost * ticks) if mytravel-budget < 0 [set mytravel-budget 0]]] ]
    set temproute nw:Weighted-path-to destination TotalImpedance]
  foreach temproute  [ the-link ->  ask the-link [ set timesused timesused + 1 ]]
  (ifelse mycar = true [foreach temproute  [ the-link ->  ask the-link  [ set timesusedcar timesusedcar + 1]]]
    mybus = true [foreach temproute [ the-link ->  ask the-link  [set timesusedbus timesusedbus + 1]]])
  if temproute != nobody  and destination != nobody [move-to destination move-to myhome]

 ]  ask links [  show timesusedbus print "timesusedbus"]
 ask links [ show  timesusedcar print "timesusedcar"]
end
to calculateMyImpedance [mycar mybus currentstation myIncarTime mywalkingtimeStation] ;; runs the total impendance with travel cost or with out it,
 ifelse Impedance = true
 [( ifelse mycar = true
   [set TotalImpedance traveltimecar + car-travel-cost + myIncarTime] mybus = true
   [set TotalImpedance traveltimebus + bus-travel-cost + mywalkingtimeStation + ([ WaitingTimeStation ] of one-of currentstation) ])]
 [(ifelse mycar = true
   [set TotalImpedance traveltimecar + myIncarTime ] mybus = true
   [set TotalImpedance traveltimebus + myIncarTime + ([ WaitingTimeStation ] of one-of currentstation) ]) ]
end

to reset
 ask persons [move-to myhome]
 reset-ticks
end
to update_travel_time
 if travel-time = true [ ask Roads [ (ifelse timesusedcar >= capacitycar
```

```
    [ set traveltimecar traveltimecar + exp (timesusedcar * 0.02)
      if traveltimecar > 120 [set traveltimecar 120]]
    timesusedcar < capacitycar [set traveltimecar traveltimecar - exp (timesusedcar * 0.02)
      if traveltimecar < 10 [set traveltimecar 10]])
  ]
  ask Roads [( ifelse timesusedbus >= Capacitybus
    [set traveltimebus traveltimebus + exp ( timesusedbus * 0.02)
      if traveltimebus < 120 [set traveltimebus 120]]
    timesusedbus < capacitybus [set traveltimebus traveltimebus - exp (timesusedbus * 0.02)
       if traveltimebus < 10 [set traveltimebus 10]])]]

end
to update_waiting_time
  if WaitingTime = true [
    ask Roads [      let mytraveltimebus traveltimebus      ifelse timesusedbus >= capacitybus
     [ask both-ends
         [set WaitingTimeStation (WaitingTimeStation + (mytraveltimebus * 0.0002))
         if WaitingTimeStation > 30 [set WaitingTimeStation 30]] ]
           [ask both-ends [set WaitingTimeStation (WaitingTimeStation - (mytraveltimebus * 0.0002))
        if WaitingTimeStation < 5 [set WaitingTimeStation 5]]]]]
end
to set-walking-time-station-and-in-car-time
  if timeToStation = true [  ask persons [(ifelse  car = true [set incartime (3.5 * mydistance) ]
      bus = true [set walkingtimeStation (7 * mydistance)])]]
end
```