ASSESSING PUBLIC TRANSPORT SUPPLY FOR KIGALI, RWANDA

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February, 2012

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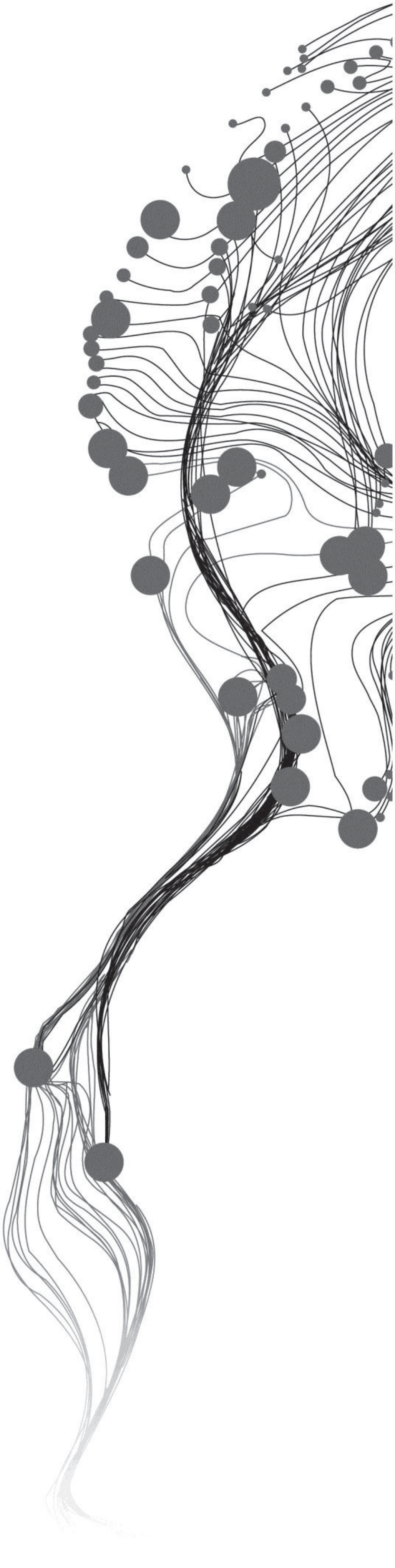

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Enschede, The Netherlands, [February, 2012]

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Specialization: Urban Planning and Management

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Dedicated

To my mother and the memory of my father
To my loved sister and her husband
To my darling, Sandrine Twagirimana

Abstract

Public transport is supplied to provide mobility to people who do not have access to private cars, or provide an alternative option to private car mobility. Nowadays, public transport is increasingly adopted for many purposes, such as providing mass mobility, managing traffic congestion, mitigating air pollution, reducing energy consumption and creating development opportunities. Notwithstanding all the stead incentives to promote the use of public transport, a critical issue remains whether public transport services are able to cope adequately with the demand for it.

In this research, particular attention has been given to the spatial and temporal aspects jointly combined with seating capacity of service supply, in order to evaluate the performance of public transport service. For a noteworthy concern in this regard, the access distance to bus stops is important. This is because if the distance to and from public transport service is large; it ceases to be useful to the people who want to use it. Additionally, the temporal aspect is of substantial value; a service within a walking distance is not considered as available if times of waiting are more than what passengers can tolerate. Likewise, if the service is insufficient to satisfy the demand, then utilization of the service is also unlikely.

The aim of this research is to assess the public transport network routing and service capacity in relation to the potential transit demand in Kigali city. To ascertain the disparity between public transport demand and available supply for public transport in Kigali City, a performance assessment was carried out. We used GIS techniques to develop a system-level performance measurement which assesses service availability in different locations of the city.

The results indicated that, the current public transport in Kigali can serve up to 65% of the potential demand, regardless of the distance required to reach the bus stops. However, only 37% of the demand is adequately served, in case both spatial and temporal aspects of service supply are considered. This low service performance is due to the deficiencies of public transport route network and the service capacity constraints. Along these, we identified these deficiencies, and we proposed also suitable roads for network expansion, and priority routes to be allocated more service capacity. Moreover, we advocate different subjects to be explored for further researches, with respect to the improvement of Kigali public transport system.

(Key words: GIS, Kigali, Performance, Public transport)

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Acronyms

AAT: Arc attributes table
ATRACO: Association of individual bus operators in Rwanda
CBD: Central Business District
DPSR: Driver-Pressure-State-Impact-Response
GIS: Geographic Information Systems
GPS: Global Positioning System
KBS: Kigali bus services
MININFRA: Ministry of Infrastructure, Rwanda
MTL: Mean Trip Length
NISR: National Institute of Statistics of Rwanda
NLC: National Land Center, Rwanda
NRF: National Road Fund, Rwanda
OD: Origin- Destination
PT: Public transport
RAT: Route attributes tables
RNP: Rwanda National Police
RTDA: Rwanda Transport Development Agency
RURA: Rwanda Utilities Regulatory Agency
SEC: Section attributes table
TAZ: Traffic analysis zone

1. INTRODUCTION

1.1. General Introduction

An innovative approach is needed to meet urban mobility challenges especially in Sub-Saharan African cities (Diaz Olvera, Plat, & Pochet, 2008; The World Bank, 2011b). Most of these cities are overburdened by a high population growth, inadequate transport and extreme poverty. The rapid population growth and urbanization, coupled with increasing economic activities and opportunities in the cities, result in rapidly growing travel demand, both for private as well as public transport.

To accommodate this rapid growth in the demand for private transport requires very extensive road capacity, which would induce more greenhouse gas emissions. Alternatively, public transport is adequate for mass mobility; it makes better use of urban space, reduces the reliance on more polluting modes of transport, and is likely to be an affordable means of transport for most residents in these cities.

The provision of adequate and appropriate public transport services is one of the most important components for well-being of growing and expanding urban areas (Murray, Davis, Stimson, & Ferreira, 1998). Experience has shown that, public transport has a great significance in reducing traffic congestion, offering alternative means of travel, and contributing greatly to the quality of urban life (Vuchic, 2005).

Public transport is a public service, and should provide service levels that comply with public demand (Soehodho & Nahry, 2006). With a growing population and rapid urbanization, public transport systems need to be updated as well. A lag between growing public transport demand and service capacity results in an increase of travel cost, congestion, and unreliable service, thereby creating economic loss and environmental degradation. Therefore, it is of substantial value that approaches for monitoring, assessing and modelling public transport system performance are developed, in order to ensure a provision of better services.

1.2. Background and research justification

1.2.1. Kigali and public transport

Kigali city, the study area of this research, is the national capital and the most important business centre in Rwanda. It has a high altitude, in a tropical climate with a mountainous landscape sprawling across ridges and wet valleys in between. Rapid urbanization in the city had resulted in unplanned settlements, urban sprawl, and increasing urban poverty. Subsequently, more than 80% of the population of Kigali lives in informal neighbourhoods (Kigali City, 2011a; The World Bank, 2011a).

The rapid growth of urban areas and population poses a problem to Kigali city. The level of infrastructure in Kigali was intended to accommodate about 450,000 people (The World Bank, 2011a), whereas the number of inhabitants of Kigali is currently almost 1,000,000 and around 60% of this population is young. This rapid growth affects the public transport sector also. The capacities of available buses for public transportation are becoming more and more inadequate in providing the required services on the face of growing demand, while public transport is the mainstay of most commuters. Due to limited extent of the public transport routes network, newly developed parts of the city are deprived of public transport service, and people have to walk long distance to access bus stops.

Considering all the changes Kigali is experiencing, much attention has to be paid to the problem of improving the public transport system, mainly in terms of the routes that should be operated and their service capacity. Figure 1 presents an overview of Kigali City growth.

The vision of the Government of Rwanda on Kigali's public transport, is to create modern infrastructure and cost effective and quality services with due regard to safety and environmental concerns under Vision 2020. Efforts will be made to increasing urban public transport services. An improved urban public transport system should by then reduce traffic congestion in the city, reduce pollution, and enable buses to maintain services throughout the day, even in remote areas (MININFRA, 2008).

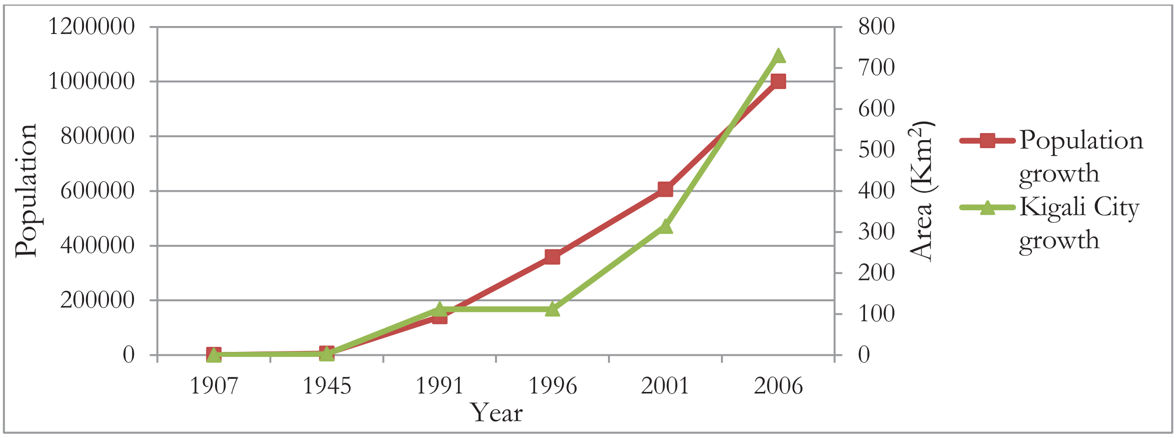


Figure 1: Kigali City growth
Source: (Kigali City, 2011c)

1.2.2. Research justification

The basic purpose of public transport has been to provide mobility to people without access to private cars. Nowadays, public transport is adopted for many purposes, such as providing mass mobility, managing traffic jams, and creating development opportunities (New Zealand Transport Agency, 2010). These have increasingly made public transport a crucial component of a sustainable and functional city. According to (State of Western Australia, 2011), public transport plays a vital role in creating competitive economies, liveable, and inclusive communities within the city. Additionally, numerous authors have also articulated that public transportation is one of the potential ways of mitigating air pollution, reducing energy consumption, improving mass mobility and alleviating traffic congestion (Chien, 2005; Grotenhuis, Wiegmans, & Rietveld, 2007; Yao, 2007).

In spite of above incentives, the benefits of public transport will be realized by having an adequate public transport system, which provide good service everywhere in a city at all times (Gwilliam, 2002). An adequate public transport should provide service for travellers with very different needs, ranging from peak-period access to the central business centre (CBD) to all-day access to local shops, recreational areas, residential areas, and community centres in order to achieve environmental and social objectives. It should also be able to provide attractive service frequencies and operating hours to a wide range of destinations. It is obvious that such public transport system can contribute evidently to urban economic performance, social cohesion and sustainable environmental outcomes (Dodson, Mees, Stone, & Burke, 2011; New Zealand Transport Agency, 2010).

For a noteworthy concern, if the distances to access a service are too great at either the trip origin or destination, then public transport is unlikely to be utilized as a mode of travel (Murray et al., 1998). Yet, the temporal side of public transport is crucial, considering that a service within walking distances is not considered as available if wait times beyond a certain threshold level are required (Bhat et al., 2006; Polzin, Pendyala, & Navari, 2002). Similarly, if the service is insufficient to satisfy the demand then utilization of the service is also unlikely. It is worth then to monitor the disparity between the public transport demand

and available capacity for public transport, on the basis of high population growth and rapid urban expansion, which is the case of most developing countries. Upon aforementioned considerations, the evaluation of public transport system deficiencies is essential to ultimately provide better services.

The ability to improve public transport services relies on the ability to measure the public transport system performance. According to (Polzin et al., 2002), the planning and operation of public transport service are closely tied to the ability to measure the spatial and temporal accessibility of the public transport systems. This raises the need for assessment of public transport network routing and service capacity available to meet the demand.

Planning and assessment of a public transport system, especially in terms of routes to be operated, and components of services capacity to meet transit demand is a complex task, and it requires a considerable analysis (Ceder, 2007; Guihaire & Hao, 2008; Iles, 2005). This greatly calls upon the use of transport models and technologies such as Geographical Information Systems (GIS) in urban transport planning (Hensher & Button, 2000). GIS have the ability to integrate maps and spatial analytical methods, which make it a powerful tool for transport planning (Lao & Liu, 2009). According to (Nyerges, 1995), GIS are proving to be valuable transportation management and modelling plat-forms. This research will by then rely on GIS based approaches to develop Kigali public transport model. Additionally, objectively verifiable indicators are needed to assess the public transport system of Kigali.

1.3. Research problem

Public transport in Kigali faces multiples challenges stemming from a mismatch between the supply of public transport services and growing transit demand. The high transit demand has been attributed to rapid and uncontrolled urbanization outstripping the capacity of public transport supply. This in turn has contributed to the insufficiency of public transport services.

Remote areas are deprived of public transport services. Where public transport services are deemed to be available, commuters are gradually getting accustomed to long queues waiting for buses at bus stops. The insufficiency of public transport supply hinders economic activities, and increases the cost of transportation in the city of Kigali. Thus, strategic modelling and analysis approaches are needed for evaluating public transport supply within the city. These would help in suggesting alternative interventions to improve the public transport system.

It is important to adopt a number of indicators to analyse the public transport system of Kigali, and get a clear picture of the causes of inadequacy of the public transport services. This research is designed in that regard. It intends to examine the extent to which the existing public transport system gives access for residents to participate in their different socio-economic activities. The research consists of the analysis of current public transport routes network and service capacity constraints.

A GIS based model should be developed to evaluate the public transport system. The approach is to identify, and analyse a number of performance indicators, and use them to develop a system-level performance measurement, in order to assess the availability of public transport service in Kigali city.

1.4. Research objectives and research questions

This research aims to assess the public transport network routing and service capacity in relation to the potential transit demand in Kigali city.

Sub-objectives and research questions

To define the performance indicators of public transport routes and service capacity

- Which factors should be considered to assess public transport route network?
- What are indicators to define public transport service capacity?

To assess Kigali public transport routes network

- What is the spatial coverage of public transport routes network?
- What is the distribution of route network within the city?
- How could we improve Kigali public transport route network?

To estimate potential transit demand

- What is the distribution of potential transit demand?

To assess service capacity of Kigali public transport system

- What is the public transport service capacity dispatched per route?
- How can we assess the distribution of public transport service capacity within the network?
- How can we determine the overall performance of public transport supply?
- How much capacity is needed to satisfy the demand?

1.5. Conceptual model

1.5.1. DPSR assessment framework

A Driver-Pressure-State-Impact-Response (DPSIR) framework was used to address the problem of inadequate public transport in Kigali. According to the DPSIR framework there is a chain of causal links starting with driving forces through pressures to states and impacts on ecosystems, eventually leading to responses. Figure 2 shows the DPSIR framework used to simplify the cause-effect relationship of inadequate public transport in Kigali, so as to generate different interventions.

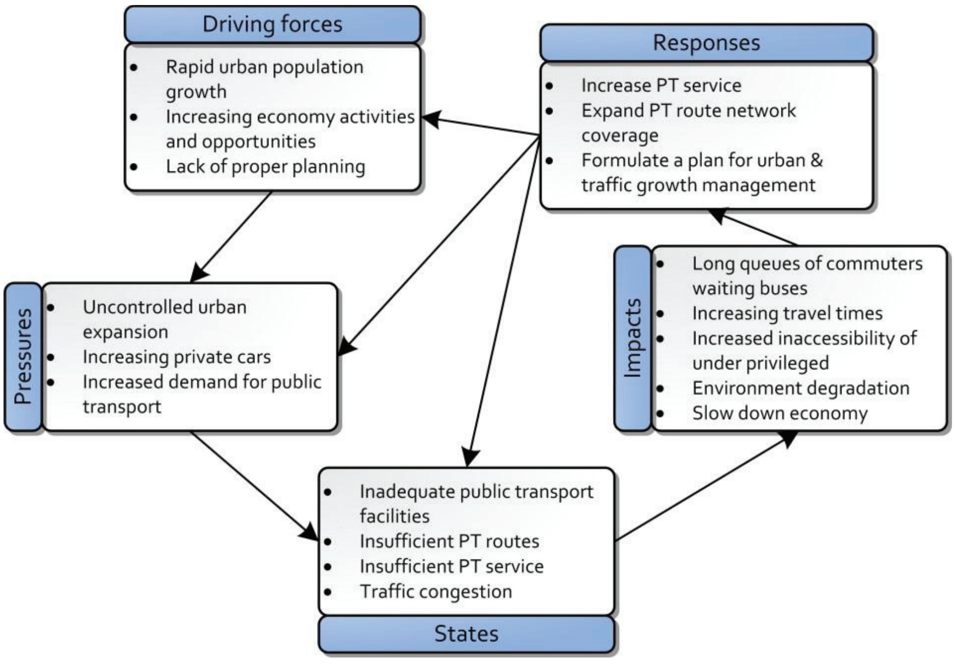


Figure 2: The DPSIR assessment framework

1.5.2. Conceptual framework

Urban public transport is designed to facilitate the movements of residents within the city. It must be able to move people from their residential areas, and enable them to participate in different socio-economic activities. In other words, public transport is required to link people and their activities..

The developed conceptual framework will help to assess the current public transport system performance, and guides the identification of improvements of public transport supply in Kigali. The set of public transport performance criteria will be based on route performance indicators and service capacity performance indicators. The given framework was adapted from (Ceder, 2007; Guihaire & Hao, 2008).

The approach starts by identifying route performances indicators and service capacity performance indicators, and ascertain data required for performance assessment. A GIS based is then developed based on adopted indicators in order to assess the performance of public transport supply in Kigali, and reveals the extent to which public transport service are available in Kigali city. On basis of the results, improvements will be identified.

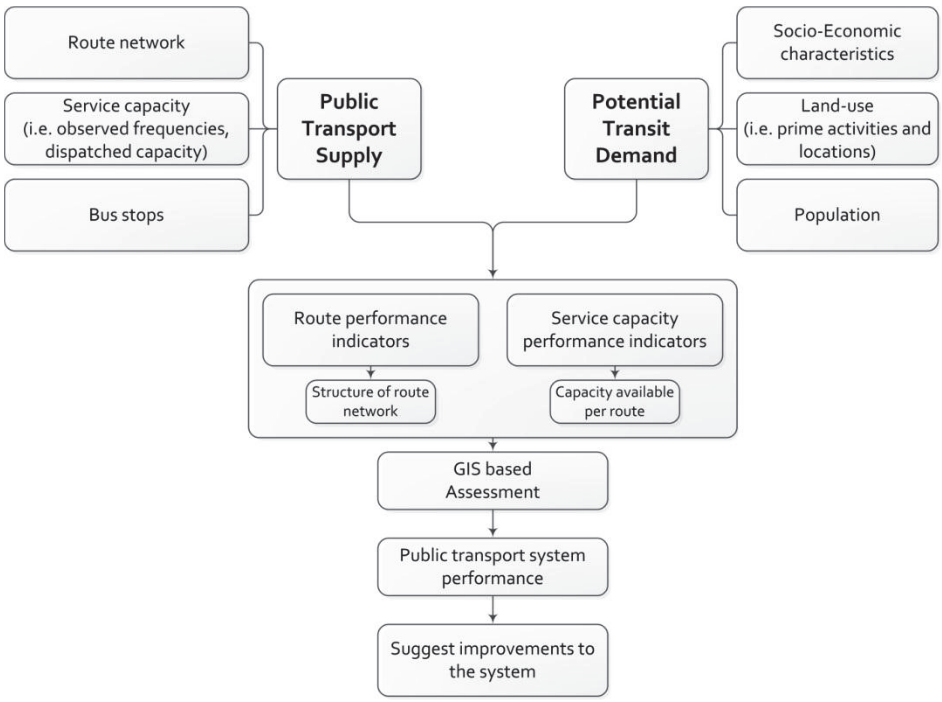


Figure 3: Conceptual framework

1.6. Research Design

The present research design illustrates the main components of the intended study and the procedures to be followed in carrying out this research. The literature review serves to scientifically define the real problem and identify research problem, objectives and research questions. It further assists to ascertain data required.
Based on a set of service performance indicators, the performance of Kigali public transport system will be assessed using spatial and statistical analysis. Later, the results help to suggest interventions leading to service improvement.

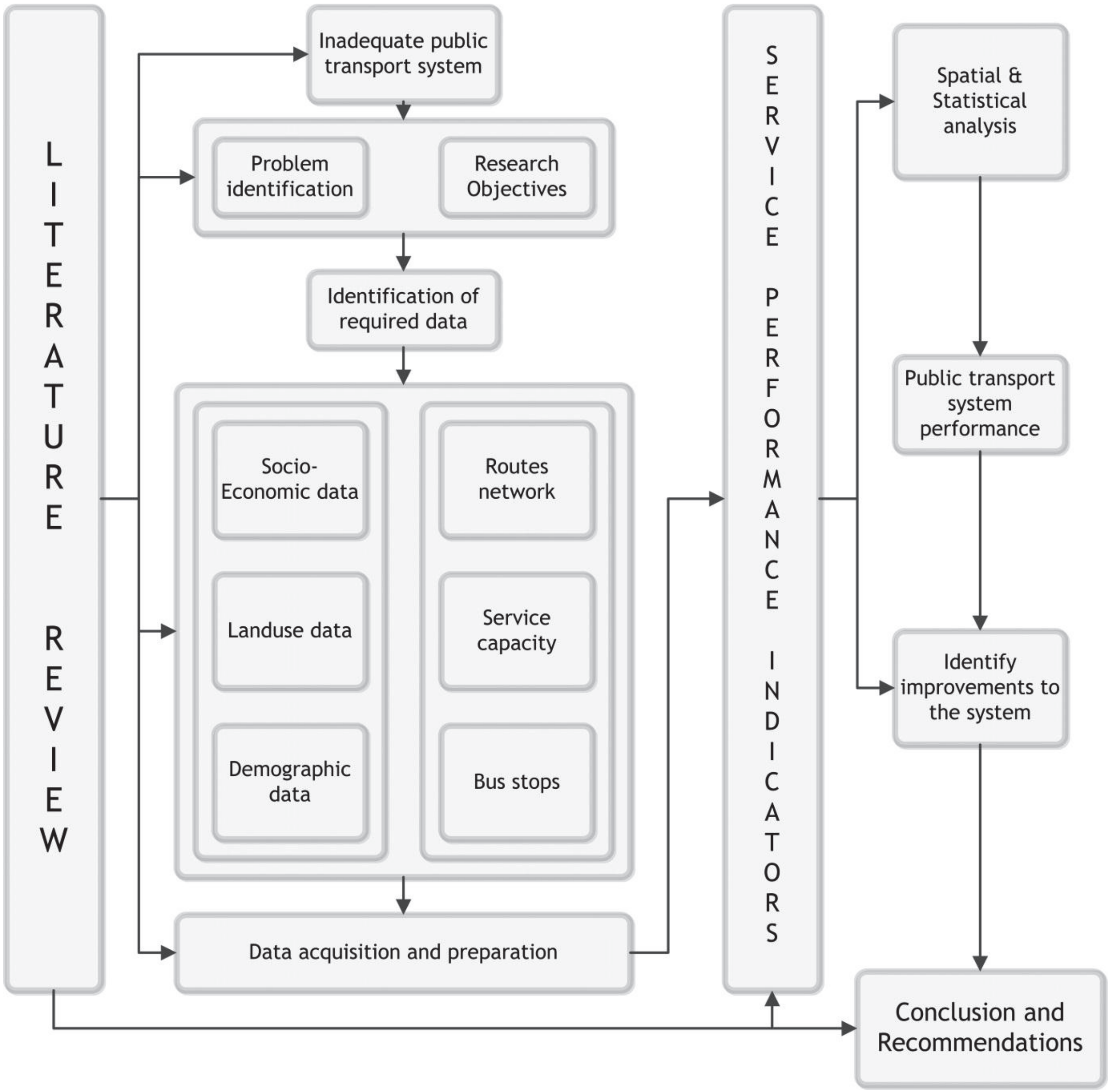


Figure 4: Research Design

1.7. Research matrix

The research matrix indicates data required, their source and methodology envisaged in order to respond each specific research objective. Data are needed for three main purposes, namely description of the present situation; input to development and use of transport models; and monitoring the effects of the implementations of policies, strategies, and investments (Hensher & Button, 2000).

Table 1: Research matrix

No.	Specific research objective	Data required	Data source	Data acquisition tool	Method of analysis
1	To define public transport routes network and service capacity indicators	Relevant literature	Secondary	Literature review	Using keywords (public transport, service capacity, routes network, performance)
		Technical (experts) reports	Secondary	Literature review	
2	To assess Kigali public transport route network	Public transport route network	Primary	Digitize routes network from 2009 orthophoto image of Kigali	GIS based analysis
		Demographic data	Secondary	NSIR (National Institute of Statistics of Rwanda)	Statistical analysis
		Bus stops	Primary	Digitization	GIS based analysis
3	To estimate potential transit demand	Land use	Secondary	Extract class of interest from orthophoto image	GIS based analysis
		Socio-economic & Demographic data	Secondary	Estimation based on demographic, socio-economic & land-use data	GIS based analysis Statistical analysis
4	To assess service capacity of Kigali public transport system	Public transport route network	Primary	Digitize routes network from 2009 orthophoto image of Kigali	GIS based analysis Statistical analysis
		Dispatched buses on a route	Primary	Recording dispatched buses from departure points	GIS based analysis Statistical analysis
		Potential transit demand	Primary	Output data from the preceding estimation	GIS based analysis

1.8. Assumptions

The demand for public transport will be based on potential transit demand due to lack of disaggregated data of travel demand characteristics in Kigali. Moreover, since there are no absolute measurable criteria for assessing public transport system, numerous authors articulated that the evaluation can be based on the passenger perspective, operators' perspective and community perspective (Ceder, 2007; Iles, 2005; Sheth, Triantis, & Teodorovic, 2007). Therefore, based on the limited time for research, the performance assessment will be based on passenger perspective.

1.9. Expected Outcomes of the Research

The anticipated research is intended to produce the following outcomes:

- It will provide the current performance of public transport system in Kigali, in terms of routes network and public transport service capacity.
- It will give insights on what, where and how to improve Kigali public transport system towards an improved access.
- A developed model of urban public transport for Kigali is expected.

1.10. Benefits of the Research

Different individuals and organizations will benefit the findings of this research:

- The findings will provide an insight on the requisite of both, capacity and structure of routes network, for performance of Kigali public transport system.
- The findings could guide decision makers and public transport providers to recognize where services are needed, so as to strengthen their service provision, and alleviate the problems of spatial inequity.
- In addition, this research will provide an opportunity to further research by individuals and organizations.

1.11. Thesis Structure

Chapter-1 briefly outlines the background and justification of the research, and led to the identification of the research problem, research objectives, research questions and conceptual framework in order to respond to the objectives of this research Assumptions and expected outcomes of the research are also discussed in this chapter.

Chapter-2 describes and defines the theoretical concept of public transport route performance indicators, and public transport service capacity performance indicators. Based on literature review, findings of other relevant studies are discussed.

Chapter-3 gives a general description of the study area which is unfolded through the physical characteristics of Kigali, and the operating environment of public transport in Kigali. The operating environment will be based on geographic and climatic factors, demographic factors, socio-economic characteristics, institutional factors, and road and traffic conditions.

Chapter-4 outlines and discusses methods and data collection techniques used from pre-field work stage to post-field work stage; it demonstrates the data analysis procedure applied, and the overall assessment followed.

Chapter-5 describes the situation of Kigali public transport system; structure and spatial coverage of route network, and the assessment of public transport service capacity using statistical and GIS based analyses.

Chapter-6 presents the overall performance, and identified improvements a better public transport service.

Chapter-7 consists of conclusion and recommendations based on analysis results.

2. URBAN PUBLIC TRANSPORT

2.1. Introduction

Life in the city depends on transport, especially for the movements of people from their places of residence to where they must go to pursue all the activities of life, such as work, education, business, shopping and leisure activities. Public transport is an effective and environmentally friendly alternative to accommodate those movements. It represents a basic service and enhances spatial relation between locations which provide diversified activities, economic vitality, and socially sound conditions. It is therefore crucial for a city to have a well-functioning and attractive public transport system to provide high quality of life and be characterized as liveable (Iles, 2005; Vuchic, 2002).

Public transport refers to a collection of modes of transport which are available to the public irrespective of ownership (White, 2002). This collection encompass several modes of public transport, namely road-based transport, rail transport including metro and tram systems, water transport, and air transport for longer journey. Road vehicles used for the provision of public transport services include conventional buses, paratransit vehicles, taxis, human and animal powered vehicles (Iles, 2005). Among these modes, the conventional buses are the most common public transport mode in developing countries in view of the fact that they offer relatively low running costs, route flexibility, and permeability into town and city centres (Davison & Knowles, 2006). As the main focus of this study, the remainder of this research is primarily concerned with performance of public transport system by bus services.

2.2. Public transport in cities in developing countries

Worldwide, an increase in awareness of the economic costs of traffic congestion and environment degradation has resulted in a focus by authorities on curbing the use of private cars, especially for commuter trips, and public transport incentives. In developing countries, public transport has more important role, because its economic efficiency is vital for large volumes of non-car owners, while its capacity is needed to serve the high-density, rapidly growing cities. These make public transport a crucial component of the city, which deserved to be adequately maintained and enhanced to meet this rapidly growing mobility needs (Badami & Haider, 2007; Vuchic, 2002).

Conversely, the existing public transport in developing countries are unable to cope adequately with the demand due to numerous factors, including inadequate road infrastructure, uncontrolled expansion of the cities, high urban population growth, low levels of income and poor traffic management (Iles, 2005).

In most cities, such as Kigali, buses have to compete for spaces with other private vehicles. This volume of mixed traffic sharing the restrain lane with buses affects bus capacity in two circumstances. First, the interference instigated by other traffic in the lane, particularly at intersections, may obstruct buses from reaching a stop or may delay a bus obstructed behind a queue of vehicles. Second, for off-line stops, the additional re-entry deferral met when buses leave a stop and re-enter traffic may affect capacity. Additionally, the speeds of buses operating in mixed traffic are influenced by bus stop spacing, dwell times, delays due to traffic signals, and those interferences from other traffic operating in the lane (TRB, 2000).

Lack of appropriate administrative framework for public transport operation and management is another hurdle leading to poor regulation of services in developing countries. According to (Iles, 2005), the principal objectives of transport regulation would be to ensure that services are operated in accordance with government policy, that demand for public transport is satisfied as far as possible, that standards of quality and safety are maintained, and that fares are controlled at affordable levels. Regulation would by then help to control potentially dangerous aspects of competition between operators. Contrariwise, deficiency of coordination between different decision-making, implementing agencies and tiers of government in developing countries induces poor regulation of public transport services (Kam, 1991).

With respect to the improvement of public transport in developing countries, much attention should be given to the planning and regulation of public transport service. If not, the public transport system is likely to be rudimentary, particularly where services are unregulated and provided by a large number of small operators (Iles, 2005; Vuchic, 2005), which is the case in Kigali, Rwanda.

2.3. Performance evaluation of Public transport system

The ability to improve public transport performance is closely tied on the ability to measure it. So far, many performance measures have been developed and used in a variety of ways (i.e. scope, emphasis and methodology), reflecting differing viewpoints and responding to differing public transport problems (Bhat et al., 2006; Isaac K, 1993).

These measures and dimensions reflect multiple perspectives such as the passenger, the service provider (i.e. operator) and community. The service providers pay attention on measures that concern with public transport system efficiency, where much emphasis is given on how well a system utilizes available labour and capital resources (Guihaire & Hao, 2008; Sheth et al., 2007). Meanwhile, these performance measures have been criticized due to the fact that they insufficiently address importance to passengers and the community at large (Kittelson et al., 2003; UITP, 2003). In contrast, public transport as a service should be passenger based, and the consideration of performance measures which are important to passenger would increase the ridership and give a way to assess the equity in service provision.

Based on the requirements for the public transport systems, their evaluation can be based on the conditions set according to different perspectives as illustrated in Fig 5.

Figure 5: Conversion of goals and local conditions set into public transport requirement

Conditions set			
Planning	Local conditions		
Goal and objectives	Physical-geographical	Economic , social, environmental	Travel demand

↓

Public transport system requirement		
Passengers	Operator	Community
Availability Frequency/Headway Punctuality Speed/travel time Comfort Convenience Security and safety User cost	Area coverage Reliability Cycle speed Capacity Flexibility Safety and security Costs Passenger attraction	Service quality/passenger attraction System cost Reliability in emergencies Social objectives Environmental impact Energy consumption Long-range impacts

Source: (Vuchic, 2005)

2.3.1. Public transport system from passenger perspective

There are two areas of greatest concern of public transport to passengers, namely service availability, and the comfort and convenience of service when it is available (Kittelson, Associates, Texas Transportation Institute, & Transport Consulting Limited, 1999; TRB, 2000). In their perspective, public transport is viewed adequate when service is available at or near the locations and at times when a passenger wants to travel. This may be realized when a passenger can get to and from the bus stops, knows how to use the service, and sufficient capacity is available at the desired time (Kittelson et al., 2003). If any of these factors is not satisfied, public transport will not be a favourable option for that trip, either a different mode may be used or the trip may not be made at all. These factors determining availability of public transport from passenger perspective can be summarized as:

- Spatial availability: is service provided, and can one get to it?
- Temporal availability: When is service provided?
- Information availability: Does the passenger know how to use the service?
- Capacity availability: Is passenger space available for the desired trip?

If service is available for a given trip, a passenger may choose public transport if its comfort and convenience are competitive with other available modes (Kittelson et al., 2003). The main determinants of comfort are vehicle design and construction, standards of maintenance, load factors, and driving standards (Iles, 2005). Aspects of convenience include accessibility, service delivery, travel time, and safety and security while using public transport.

2.3.2. Public transport system from operator perspective

Though the system must be designed and operated so that it meets passengers' requirements, its operation must be economical and technically efficient. To achieve that, operators have a set of requirements that differ somewhat from those passengers have; although some items may overlap but have different forms(Vuchic, 2005). The most concern of operators in respect to public transport is the organizational performance. This performance is mainly based on cost-efficiency indicators (e.g., operating expense per vehicle revenue kilometre and/or hour) and cost-effectiveness indicators (e.g., operating expense per passenger kilometre and/or passenger trip). These indicators seek to evaluate how well the service is working, with an ultimate goal of providing service along a route that minimizes the operating costs (Kittelson et al., 2003; Sheth et al., 2007).

From an operator perspective, services along bus routes are further defined in the context of inputs used and outputs provided (Sheth et al., 2007). The inputs considered are headway, service duration, costs, number of intersections, and number of priority routes to serve. The outputs are considered as average traveling time; which is the passenger volume transported by average trip length given by passenger-km; and vehicle productivity given by vehicle-km, which is the total distance travelled by buses in services. Their efficient concept seeks to maximize the average passengers transported by minimizing the total operating costs.

$$\text{Efficiency} = \text{Output quantity produced}/\text{Input quantity produced}$$

(Tone & Sawada, 1990) categorized these efficiency measures converted in the form of inputs to outputs based upon the resources used, e.g., financial resources, production resources, service resources, and utilized resources (utilized services). The different categories of efficiency were classified to facilitate the evaluation of performance of bus enterprises. Table 2 shows the efficiency classification from an operator perspective.

Table 2: Efficiency classification from operator perspective

Category	Input	Output
Service efficiency	Number of buses, employees	Distance covered (Service coverage)
Cost efficiency	Operating expenses	Number of buses and employees
Income efficiency	Number of buses and employees	Operating income (annual)
Public service efficiency	Number of cars and employees	Density of service (average daily service frequency)

Source (Sheth, 2003)

The challenge of this organizational performance based on efficiency measures resides that in numerous instances, the outputs in case of operator is viewed as the inputs in case of passenger, which reflect a contrasting view of efficiency (Sheth et al., 2007). Therefore, a tradeoff needs to be made to meet the social-welfare role of public transport. The consideration of passenger oriented performance measures would prevent that public transport service provision be solely based on profit making (Bhat et al., 2006; Guihaire & Hao, 2008).

2.3.3. Public transport system from community perspective

Residents are concerned with costs and negative aspects of public transport service. For these reasons, a community perspective is considering targets with respect to externalities or societal variables such as air quality, noise pollution, natural resources and safety. In this respect, the performance of public transport is met when externalities induced in the provision of service are minimized (Sheth et al., 2007). According to (Dodson et al., 2011; Kittelson et al., 2003), public transport service benefits the community as a whole when it can contribute to social cohesion and sustainable environmental outcomes. These would be reflected in many ways such as:

- Provision of transportation to persons without ready access to a private automobile, including seniors and persons with disabilities;
- Reduction of air pollution;
- Provide mobility to people without access to car;
- Parking congestion mitigation;
- Reduction of traffic congestion; and
- Job accessibility for those who are economically disadvantaged.

2.3.4. Which perspective to be considered?

By considering different performance measures, it is viewed that what is important and vital in the performance and delivery of public transport service depends significantly upon the adopted perspective. This make public transport performance a broad term since it depends upon how it is defined; and consequently, its evaluation becomes a complex task. This complexity will even much arise when multiple factors and goals are considered concurrently.

The fact that underlying goals and objectives of measurement differ, and at some point in contrasting manner, trade-offs among these considerations need to be made (Bhat, Guo, Sen, & Weston, 2005; Guihaire & Hao, 2008; Sheth et al., 2007). However, the level of service should be mainly based on passenger perceptions because their point of view is very relevant for evaluating the performance of a public transport service (Eboli & Mazzulla, 2011; Ndoh & Ashford, 1994).

Passengers are the customers for whom the system is provided (UITP, 2003). Operators depend then on their passengers. Therefore, the operators should meet passenger requirements and strive to exceed their expectations (Eboli & Mazzulla, 2011; Kittelson et al., 2003; Vuchic, 2005). Based on this view, this study will examine the level of access of passengers to public transport service in Kigali. The assessment will unfold using performance indicators of public transport routes and service capacity, with a specific emphasis on passenger perspective. Performance indicators of public transport routes seek to identify where service is provided while performance indicators of service capacity reflect how much and when service is provided, and both should be used to obtain a more complete picture of public transport service availability (Kittelson et al., 2003)

2.4. Public transport network

2.4.1. Overview of public transport network planning

The network of routes with their stops represents the principal infrastructure component of each public transport system(Vuchic, 2005). A public transport network describes the spatial and temporal relationship between the routes of connection provided by the system. Route network, including bus stops, defines the level of spatial availability of public transport service. In this concept, public transport accessibility or spatial availability is defined as how convenient is to get to different points in the area under consideration (Bhat et al., 2006).

The empirical evidence suggests that attainment of a high level of public transport service is most likely to be achieved if public transport networks are designed to serve multiple passenger cohorts and diverse travel demand patterns (Dodson et al., 2011). The more ubiquitous the network is and the more it is designed to be seamlessly interconnected, the more likely it is to serve a multiplicity of passenger trip making desires.

Bus stop and interchange design is also an important factor to ensure passenger safety, comfort and ease of use. Public transport routing should then include planning for the location and design quality of stops and the ease of access to stops, focusing on convenience for pedestrians. Thus, stops should be located as closely to activity nodes as possible and pedestrians should have access precedence over private car modes (Davison & Knowles, 2006; Iles, 2005).

2.4.2. Assessment of public transport route network

Public transport network design corresponds to the first step of the public transport planning process. Well-designed public transport provides a network of services that enables a wide array of potential trips.

It is self-evident that the public transport routes operated should be designed to satisfy as far as possible the requirements of the passengers. From passenger perspective, public transport network should cover a large service area, be highly accessible, offer numerous direct-through trips, hardly deviated from shortest paths, and should globally be able to meet the demand (Guihaire & Hao, 2008).

There are numerous performance and service criteria used in the public transport route evaluation process. These criteria serve as indicators that assess the quality and quantity of service offered by a public transport system's bus routes (Benn, 1995). In the course of this study, performance indicators will be used to assess the deficiencies in public transport routes provision in Kigali. Given the limited time of research, the scope of this study will primarily focus on evaluation of public transport routes at the network level. Table 3 indicates the adopted indicators for route performance assessment

Table 3: Route performance indicator at network level

Indicator	Definition	Threshold	Description
Service coverage	$S.C = \frac{p}{P}$ p: population served in the certain buffer area of a stop P: total population of a study area	Max 400 – 800 m walk to bus stop, however a max of 1000 m may be acceptable in low density areas	It influences public transport system's accessibility, performance and level of service, which reflects the convenient degree of public transport.
Network density	$N.D = \frac{l}{A}$ l: total length of road passed by bus routes A: land-use in bus service coverage	3 – 4 km/km² nearby the CBDs. 2 – 2.5 km/km² in the suburban areas	It describes the degree of consistency between potential users and public bus routes.
Route overlapping	$R.O = \frac{l}{L}$ l: total length of bus routes L: total length of bus route network	The ratio should be kept low than 5. High route overlap is likely to induce traffic jam	It reflects the repetition of bus routes to ensure public transport services within a service area have adequate and rational distribution.
Average bus stop spacing	$A.S.D = \frac{l}{(n-1)}$ l: length of a bus route n: total number of bus stops passed by this bus route	300 - 600 m, it is subjected to vary according to population density and land-use	It reveal whether the bus stops are redundant or insufficient

Indicators adapted from (Armstrong-Wright & Thiriez, 1987; Benn, 1995; Ceder, 2007; Guihaire & Hao, 2008; Iles, 2005)

2.5. Urban public transport capacity

2.5.1. Overview of public transport service capacity

The assessment of public transport route network evaluates public transport service solely based on spatial access to stops or routes, and do not address the temporal dimension associated with the availability of public transport service (Bhat et al., 2006). Yet, the temporal aspect of public transport availability is important because a service within walking distance is not necessarily considered as available if wait times beyond a certain threshold level are required. This wait time for public transport is related to the frequency of the service as well as the threshold for tolerable waits for potential riders (Polzin et al., 2002).

Measures of capacity are candidates for measuring service availability and service delivery (Bhat et al., 2005). Capacity addresses the number of people and/or public transport buses that can be served consistently in a given amount of time. The low service capacity of public transport is likely the most source of inadequacy of a public transport system.

In this line, public transport service availability is examined in terms of hours of service, service frequency, capacity availability and spatial access (Kittelson et al., 2003; Polzin et al., 2002). Service frequency determines how many times an hour a passenger has access to the public transport. Service frequency measures also the convenience of public transport service to passengers, and is one component of overall transit trip time (Yaliniz, Bilgic, Vitosoglu, & Turan, 2011). However, the service measure used is usually average headway, which is the inverse of the average frequency

2.5.2. Public transport service capacity evaluation

Capacity measures reflect the public transport system ability to meet existing demand and to determine the ultimate number of people or public transport vehicles that can be served by public transport facilities. Passenger demand that approaches or exceeds a system's capacity is likely to impact quality of service, as reliability tends to suffer, transit speeds decrease, and passenger loads increase (Kam, 1991; Kittelson et al., 2003).
There are two important different capacities for public transport systems: vehicle capacity, expressed in spaces per vehicle, and the route capacity, which represents the actual capacity offered to passengers in spaces transported past a fixed point in one direction per hour (Vuchic, 2005). Since buses in Kigali operate in mixed traffic as there are no specific lanes solely designed for public transport, the route capacity will be based on the seating capacity of operated buses along a route.

In the course of this study, service capacity of a public transport system is determined based on offered services by the system. The basic elements describing services a public transport system offers to the public are the numbers of buses in service, speeds, and headways or service frequencies (Vuchic, 2005). These indicators would determine how often service is provided and the capacity available. The assessment of operating speed coupled with route capacity will reflect the productive capacity of the public transport system, which affects both passengers and operators. Table 4 indicates adopted indicators for service capacity performance assessment, and Figure 5 indicates their acceptable thresholds.

Table 4: Service capacity performance indicators

Indicator	Definition	Description
Seat capacity	$S.C = \frac{SxV}{A}$ *S*: number of seats on a public transport bus *V*: number of buses in service *A*: service area size	It reflects the planning-level estimate of the capacity offered by the system. The service area size represents potential transit demand in the unit considered
Observed frequency	$O.F = \frac{V}{t}$ *V*: public transport buses *t*: time unit	Observed frequency reflects the amount of service provided. It further determine the span of service which in turn impacts the convenience of transit for passengers and can constrain the types of trips that can be made by public transport.
Average network speed	$A.N.S = \frac{\sum_i V_i S_i}{\sum_i V_i}$ V_i: number of bus-km operated per day or per hour S_i: travel speed of bus	It is the average speed (km/h) that buses travel while in service. System speed may be measured by time of day, length of trip, or portion of a service area

Indicators adopted from (Kittelson et al., 2003; Vuchic, 2005)

Table 5: Threshold of identified service capacity performance indicators

Indicator	Condition	Threshold
Headway upper limit	Peak period	Max 15 – 30 minutes
Headway upper limit	Off-peak period	Max 20 – 60 minutes
Headway lower limit	-	Min 2 – 3 minutes
Service span	-	18 – 22 hours
Operating speed	Dense areas in mixed traffic	10 -12 kph
Operating speed	Bus-only lanes	15 -18 kph
Operating speed	Medium-to low-density areas	25 kph

Adopted from (Armstrong-Wright & Thiriez, 1987; Ceder, 2007; White, 2002)

2.6. Potential transit demand

Primarily, studies have proved land-use and socio-economic characteristics among the main factors determining the transit demand (Zuidgeest & van Maarseveen, 2011). Meanwhile, some studies also find other contributing variables such as the spacing between stops, level of service of the public transport system, and other sets of external factors (Ceder, 2007; Yao, 2007). These studies usually lead to the establishment of transit demand in the form of Origin-Destination (OD) matrices. OD matrices constitute an essential input for most transit planning and design procedures (Ceder, 2007).

Moreover, transit demand is time-dependent and elastic, it vary with the time of the day (peak/off-peak period), day of the week, and time of the year. Detailed OD matrices should provide data according to uniform demand time periods, and a good representation should be based on a survey in which passengers are asked directly about their precise origin and destination (Ceder, 2007). Since collecting this data is a very complex and expensive task (Guihaire & Hao, 2008), several methods deal with situations in which data from the surveys are not available such as passenger on-off counts, popularity and propensity based, and the determination of potential transit demand.

Potential transit demand for public transport refers to the kind of demand that is not explicitly expressed or realized but will be present if condition permits, for example when public transport facility is accessible (Yao, 2007). The estimation process of the demand for public transport services normally involves using GIS to identify, map and analyse census data surrounding public transport facilities and routes (Lao & Liu, 2009). This approach will then be used in this study to estimate the potential users of public transport in Kigali.

2.7. Basic operating elements

This section consists of definitions of different terms and concepts used in public transport and spatial representation of data, which we utilized throughout this research. These definitions were adopted from (Armstrong-Wright & Thiriez, 1987; Ceder, 2011; Michael F, 2011; Vuchic, 2005; Zhengdong & Masser, 2002).

- **Bus line**: a bus line is the infrastructure and service provided on a fixed alignment by buses. Although a bus line may operate in two adverse directions, it is usually represented with a single and non-directional route in transport planning and also in computer databases.
- **Bus route**: a bus route is the link between two end-terminals; a bus route may have two lines representing the two adverse directions.
- **Bus stop**: bus stop is a location along a line at which buses stop to pick up or drop off passengers.

- **Ecological fallacy**: error of assuming that correlations observed for aggregates can be assigned to the individual. It is used in
- **Headway**: headway is the time interval between two successive transit units (i.e. buses, trains, etc.) passing at a fixed point. It reveal how often users are served along a particular route.
- **Line length**: a line length is the one-way distance between the two terminals along the line alignment.
- **Mobility**: mobility refers, in this study, to the ability to move from one location to another, for a specific purpose.
- **Network length**: it is the total length of all alignments served by one or more lines
- **Offered capacity**: it is the maximum number of seats in buses that can be transported past a point in one direction per unit of time
- **Operating speed**: it is the average speed taking into account running speeds, delays in traffic, and stopping on route to enable passengers to board or alight.
- **Running time**: it is the time taken for a bus to travel from one terminal to the other
- **Transit**: transit refers, in this study, to public transport
- **Travel time**: it is the duration of individual time interval in public transport system operation.
- **Utilized capacity**: it is the maximum number of seats of persons who are actually transported per direction per unit of time.
- **Bus (seating) capacity**: maximum number of spaces for passengers than a bus can accommodate. This is the total seats plus the maximum allowable standees, in case it is applicable.
- **Waiting time**: it is the time between passenger arrival at a stop and the time of his (her) bus departure. With a consideration of operating conditions of public transport in developing countries, a reasonable waiting time should be in the range of 5 to 10 minutes, with a maximum waiting time ranging from 10 to 20 minutes.

2.8. Related work

A lots of studies have been carried out to assess performance in public transport industry (Armstrong-Wright & Thiriez, 1987; Badami & Haider, 2007; Chen, Yu, Zhang, & Guo, 2009; Geerlings, Klementschitz, & Mulley, 2006; Isaac K, 1993; Karlaftis & McCarthy, 1998; Nakanishi & Falcocchio, 2004; White, 2002), but little attention has been given to the spatial aspects of a public transport system, such as the characteristics of local population, transportation network, and rigorous process for determining the most appropriate performance linked to passenger-oriented and community issues (Kittelson et al., 2003; Lao & Liu, 2009). This process would provide a context, or framework, to select and apply appropriate performance indicators and measures that are integral to public transport system decision making (Kittelson et al., 2003).

Actually, few studies have been conducted considering a passengers' point of view for evaluating public transport service performance. In consideration of different perspectives including the passenger perspective, (Sheth et al., 2007) assessed the provision of bus services along different routes that comprise a public transport network. The authors expanded the existing approaches of the network model and goal programming in Data Envelopment Analysis (DEA) to capture the relationship among the operator and the user of the transportation services as well as the externalities (e.g., emissions, noise pollution, etc.) related to the transportation investment. This proposed approach enables the decision maker not only to optimally allocate resources across the public transport network but to achieve targets for societal variables that represent the environment in which the bus services are provided.

Based on the ability of geographic information systems (GIS) to integrate digital maps and spatial analytical methods, (Li, Wang, & Zhou, 2008) has applied GIS technology to analyse the readjustment effect of the public bus network from the aspects of bus routes and bus stops. The authors developed indexes based on line length, network density, repetition coefficient, nonlinear coefficient, stop density, average distance between stops, and stop coverage to reveal the characteristics and the existing problems of the present public bus network in Beijing, China.
Moreover, (Lao & Liu, 2009) integrated DEA and geographic information systems (GIS) to evaluate the performance of bus lines within a public transport system, considering both the operations and operational environment. Doing so, they managed to examine the operational efficiency and spatial effectiveness of a public transport system in the Monterey-Salinas, USA.

The work of (Polzin et al., 2002) addresses the spatial aspect coupled with the temporal aspect of public transport demand and supply, for planning and evaluating public transport service. The authors developed an analysis tool of public transport accessibility and availability, which provides a measure of the share of trips for which a public transport option is reasonably available at the originating trip end.
A similar research was previously carried out by (Henk & Hubbard, 1996). These authors developed an index to gauge public transport availability based on public transport service coverage, frequency of public transport service, and public transport system capacity. However, the index was not intended for use in public transport system performance, rather a planning tool to facilitate the comparison of public transport availability over time between urban areas with similar demographic characteristics.

Recently, (Mavoa, Witten, McCreanor, & O'Sullivan, 2012) expended current public transport accessibility measures by including all components of public transport journey, calculating accessibility at the parcel level and providing a measure of public transport service. These measures enable to identify areas where is feasible for people to substitute non-car modes of travel and maintain a reasonable level of accessibility to potential destinations using the existing public transport system in Auckland, New Zealand.

Succinctly, different aspects of performance measures have been tackled which gives more insight on performance assessment of public transport system. However, performance measures including the capacity of public transport service available are needed, because a high frequency of buses doesn't necessarily translate that the capacity of service is enough to meet the demand. Yet, the size of buses is an important aspect to be addressed, particularly in informal public transport system dominated by a large number of small operators with different bus sizes, which is the case in Kigali. This research will incorporate spatial and temporal analysis of public transport service jointly combined with the available seating capacity to meet the demand. This would give a picture of public transport service available to adequately meet the demand. This research will build on the existing literature to develop such performance measurement tool.

2.9. Concluding remarks

Maintaining and enhancing public transport service in developing countries cities is imperative to meet the rapidly growing mobility needs. Yet, the existing public transport supplies are unable to cope with the growing demand. Performance measures which address importance to passengers are therefore required to analyse the deficiencies so as to ultimately provide better service. In this respect, an ability to quantify the service availability in a manner that accounts for both spatial and temporal aspects of service supply would offer the possibility to obtain a more complete picture of the allocation of service in various locations within the city. This work builds on previous studies to develop such performance measurement. In this chapter, route performance indicators and service capacity performance indicators which are relevant in Kigali were identified to respond on that regard.

3. STUDY AREA DESCRIPTION

3.1. Background of the study area

Kigali is the primary city of Rwanda, with approximately 45 per cent of Rwanda's urbanized population. It is located almost in the centre of the country, and its geographical position is on Latitude 1º 57'South and on longitude 30º 04' Est. It started in 1907 under the advice of Dr Richard Kandt, the first European resident of Rwanda, as a small Germany colonial outpost with little link to the outside world. During the First World War, Germans lost Rwanda, since on May 6, 1916, Belgian troops entered Kigali and declared victory over them (Kigali City, 2011b).

The growth of Kigali under Belgian rule was very slow, and was contained primarily on the top of the Nyarugenge hill. When Rwanda gained its independence on July 1st, 1962, Kigali remained a small village with primarily administrative functions. In 1962 the population was 5,000 to 6,000 people and the urban area of Kigali was approximately 3 square kilometres. From 1962 to 1984, the population and the built area of Kigali expanded rapidly. The population grew at around 16% from around 6,000 people to nearly 160,000, and the built area expanded also to 15 square kilometres (Kigali City, 2011a; OZ Architecture, EDAW, Tetra Tech, ERA, & Engineers without Borders, 2007).

Today, Kigali City has come of age-as the capital of Rwanda and made phenomenal strides. It is a city that has not just survived, but has prevailed and has grown into a modern metropolis- a heart of the emerging Rwandan economy and a pride of every Rwandan, which accommodates around 1,000,000 people over 730 square kilometres. Kigali consists of 3 districts, namely Nyarugenge, Gasabo and Kicukiro. These districts are divided also into sectors, which in return are divided into cells which are further subdivided into Imidugudu literally villages. Thereby, Kigali is divided into 35 sectors, 161 cells and 1061 Imidugudu (Kigali City, 2011a).

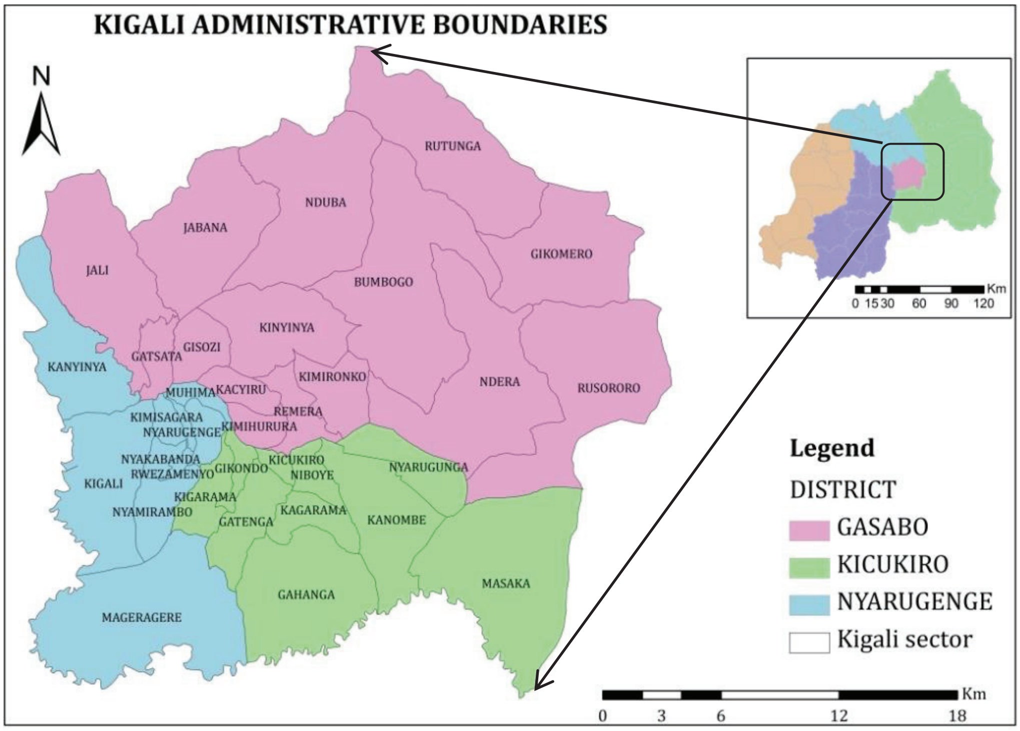


Figure 6: Kigali administrative boundaries

3.2. Physical characteristics

3.2.1. Land Use

According to the Kigali economic development strategy (Kigali City, 2002), the total area of Kigali City in 2002 was around 349 km^2. Currently, Kigali City area is around 730 km^2, comprised of 25% of urban (i.e. built up) area and 75% of rural area. These figures are a result of the national administrative boundaries reform occurred in 2005. Contrary to Figure 1, Table 6 and Figure 7 solely illustrate the growth of urban area in Kigali City since 1962.

Table 6: Kigali urban area growth

Year	1962	1984	1999	2005	2011
Population	6,000	160173	354273	566089	711570
Built-up area (Km^2)	3	15.19	45.13	65.53	175.8

Source (OZ Architecture et al., 2007)[1]

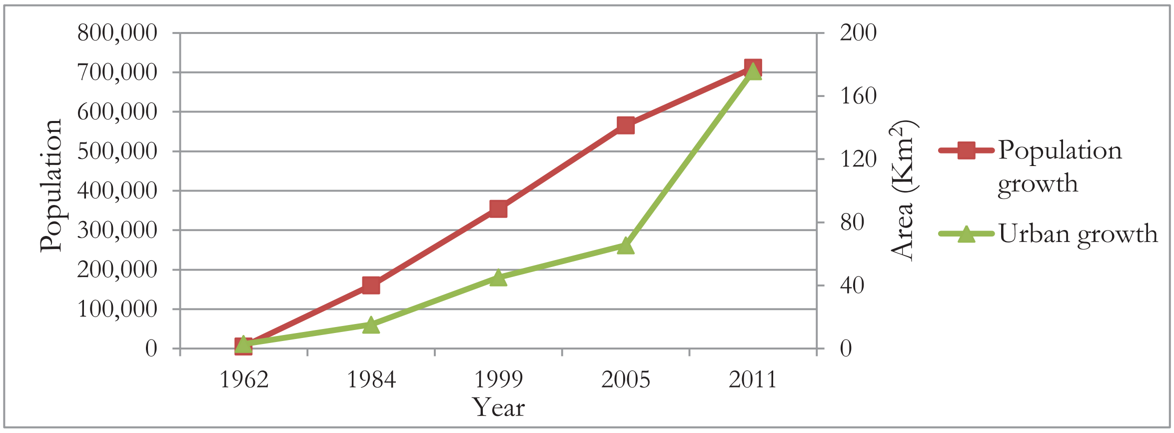


Figure 7: Kigali urban area growth

Population pressures have created two types of urban neighbourhoods. Densely populated informal settlements are remarkably sensitive to the topography, and they have inadequate infrastructure. In the second type of urban neighbourhood, returnees and internal migrants have randomly developed their homes with a "suburban" quality that tends toward sprawl. As matter of facts, the existing city development portrays a largely unplanned mixed use settlement, except in industrial areas where these uses are likely to be more concentrated or organized settlements (OZ Architecture et al., 2007; The World Bank, 2011a).

The findings are that scattered and unplanned development require attention in terms of retrofitting infrastructure into informal settlements, but this give opportunities to identify settlement clusters in less densely populated zones (OZ Architecture et al., 2007).

[1] The data for 2011 are resulted from field data collection, only the remaining are from the coted source

3.2.2. Topographic characteristics

The city of Kigali has a high altitude, sprawling across about four ridges and the valleys in between, within an average elevation from 1335 m to 2050 m above sea level. Within its elevation variation of 715 meters from highest to lowest points, the terrain of Kigali is an undulating landscape of steep hills punctuated with narrow elongated wetland basins that snake through the hilly, steep terrain. Because of the varied elevation of Kigali, topography and steep terrain are the most limiting natural constraints for infrastructure development (OZ Architecture et al., 2007).

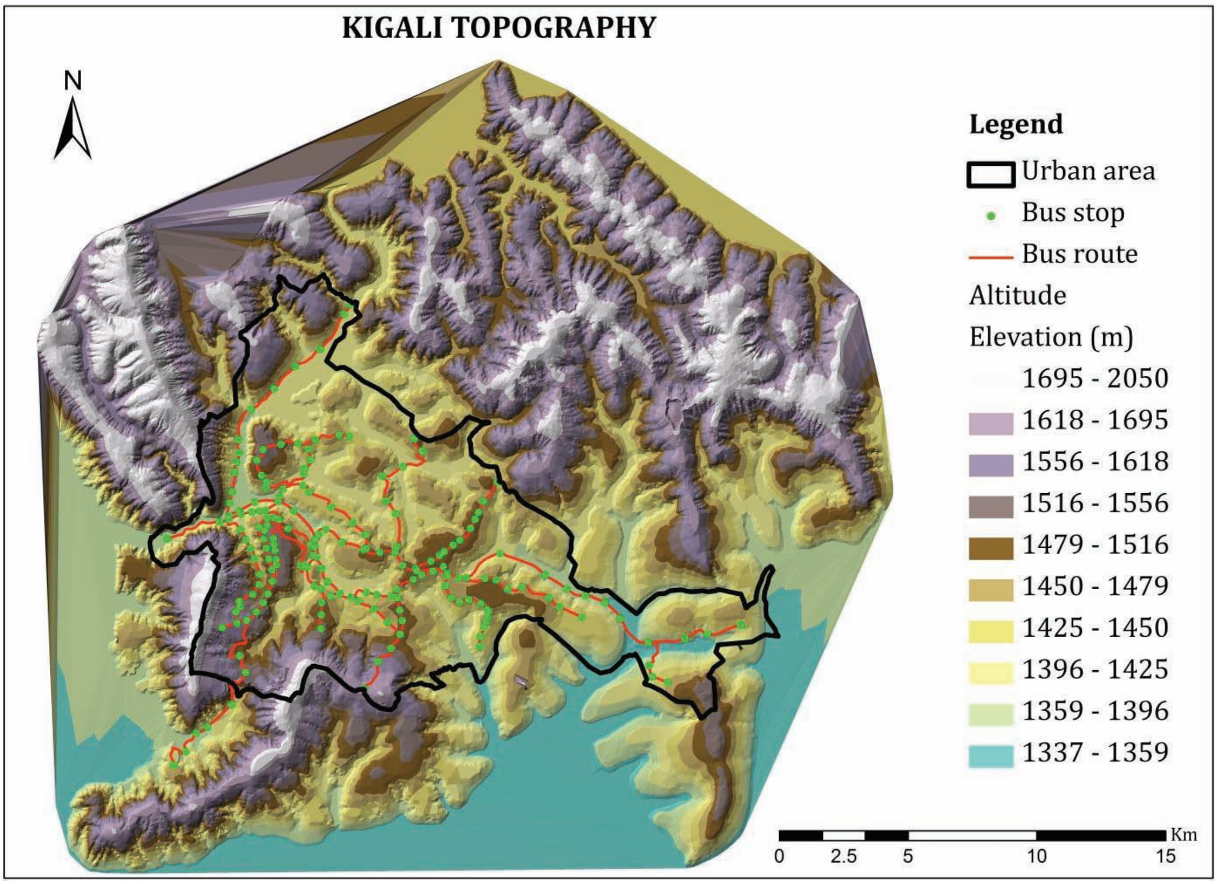


Figure 8: Kigali topographical map

3.3. Demographic characteristics

The population of Kigali in 2011 is approximately 988,330. This figure was extrapolated from a population of 851,024 in 2008 according to the Kigali Districts statistics and 608,141 in 2002 according to the 2002 national census. In addition to the normal high population growth rate, this phenomenal population growth was exacerbated by the provincial reorganization at the end of 2005 which extended the boundaries of Kigali city. Of this total, approximately 60 per cent live within the urbanized area of Kigali, which is just 30% of the total area of Kigali.

Rwanda's demographics show that it is young, densely populated, and less urbanized than many developing countries. As of the 2008 District baseline of Kigali districts, 37 percent of the population was under the age of 15, and 74 percent of the population was under the age of 30. Densities range from a low of 1-2 dwelling units (DU) per hectare in the outlying regions to a high of 62 DU/hectare in the city center.

Table 7: Kigali population distribution by age

Age Cohort	Population	Percentage	Cumulative percentage
0 - 14	314959	36.5	36.5
15 - 29	324461	37.6	74.1
30 - 44	148663	17.2	91.3
45 - 59	52761	6.1	97.4
60 - 74	16293	1.9	99.3
75+	5738	0.7	100

Figure 9 shows 10 quantile classes of Kigali population density at cell level. It illustrates that 30% of the cells have more than 4942 population per square kilometre, which would reflect the population of Kigali City, since these cells represent almost the urban area of Kigali.

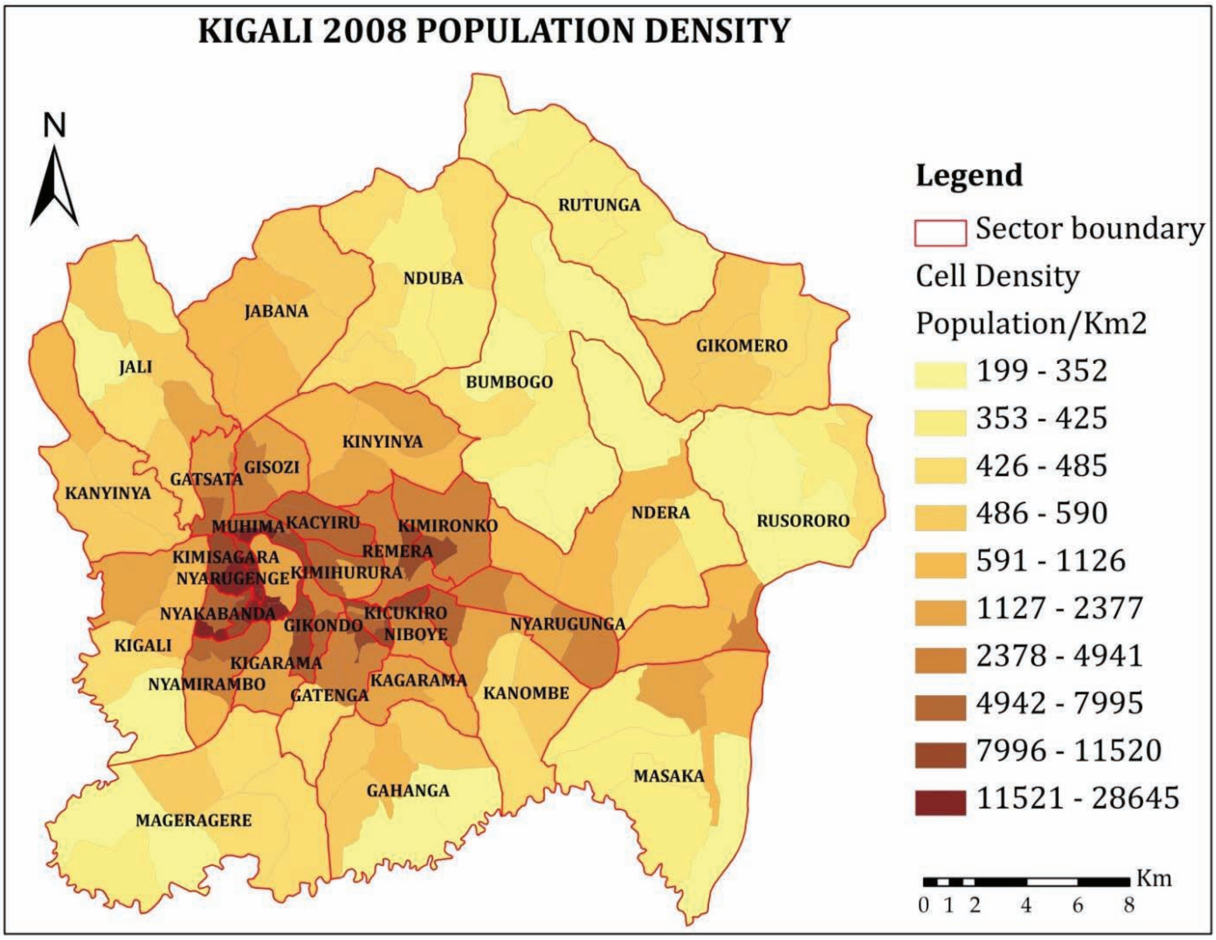


Figure 9: Kigali 2008 population density

3.4. Socio-economic characteristics

Rwanda's economy depends primarily on subsistence agriculture, with an annual gross domestic product (GDP) per capita of under Rwf 165,000 (USD $300) as per 2005 figures, and nearly 90 per cent of the population engaged in agriculture as their primary occupation. The Rwandan government has been working on a number of fronts to continue this performance and develop the economic, social, and political infrastructure of the country. Among the goals of Vision 2020 is to achieve an annual per capita

GDP of Rwf 495,000 (USD $900) by 2020, which implies a real growth rate of approximately 8 per cent annually(OZ Architecture et al., 2007; Republic of Rwanda, 2000).

The importance of these numbers for residents of Kigali takes on nuanced meaning when income distribution analysis is applied. Although Kigali has the highest income range in Rwanda, there would still be a range of annual GDP per capita by 2020, even under the best economic conditions, that would vary from Rwf 68,200 (USD $124) in the lowest decile to Rwf 1,100,000 (USD $2,000) in the highest decile. These findings demonstrate an ecological fallacy, and the implication is that even with substantial economic growth, urban vitality will require extremely efficient, cost effective and strategic infrastructure planning that will allow for extremely innovative and entrepreneurial economic growth (OZ Architecture et al., 2007).

While, the current economic base of Rwanda is agriculture and tourism, the situation is rapidly changing in the urbanized areas. The service sector is increasingly gaining importance in the urban areas, with banks and multinational organizations moving their offices to Kigali. This has generated numerous diversified employment opportunities within the City, but still the informal sector has a great share as it involves around 60% of the population. The remaining occupied populations working in formal sector are distributed in economics sector as follows:

- 13% are government staffs with 35% as female
- 8.3% are businessman or shopkeepers (formal commerce) with 46% as female
- 4.8% working in agriculture and farm (breeding) primary sectors with a proportion of 73% as female
- 14.4% working in formal private sector where men dominate with a proportion of 63%

Table 8 of Kigali household income shows that the housing revenue made of principal and secondary activity of housing chief and his spouse remains low.

Table 8 Kigali household income

Housing revenue category	Percentage
Less than 50,000 Rwf (USD $91)	49.8
Between 50,000 Rwf (USD $91) and 100,000 Rwf (USD $182)	22.4
Between 100,000 Rwf (USD $182) and 250,000 Rwf (USD $454)	9.9
More than 250,000 Rwf (USD $454)	3.9

Source (MININFRA, 2011)

3.5. Operating environment of public transport

3.5.1. Road network

The current road network in the City of Kigali consists of 732 km of roads, of which only 14% is paved. Less than 1% of the roads are constructed with granite-pavers, and the rest is rough dirt. The nature and extent of public transport services is influenced by the characteristics of the road system, which is inadequate in terms of both condition and capacity. Where roads are poor, most transport operators are deterred from providing all but a basic service, while a good road system is likely to encourage the development of bus services (Iles, 2005).

Table 9: Rwanda road network

RWANDA ROADS	Length (km)	Road density (km/km²)
Classified Road		
Total paved national roads	1,075	0.04
Total unpaved national roads	1,785	0.07
Total unpaved District roads	1,838	0.07
Total classified roads	**4,698**	**0.18**
KIGALI CITY ROADS		
Total paved road in Kigali City	153	0.21
Total unpaved roads in Kigali City	864	1.18
Total Kigali City roads	**1,017**	**1.39**
Rural feeder roads		
Total unpaved feeder roads	**8,285**	**0.31**
Grand total of roads in Rwanda	**14,000**	**0.53**

Source: (MININFRA, 2011)

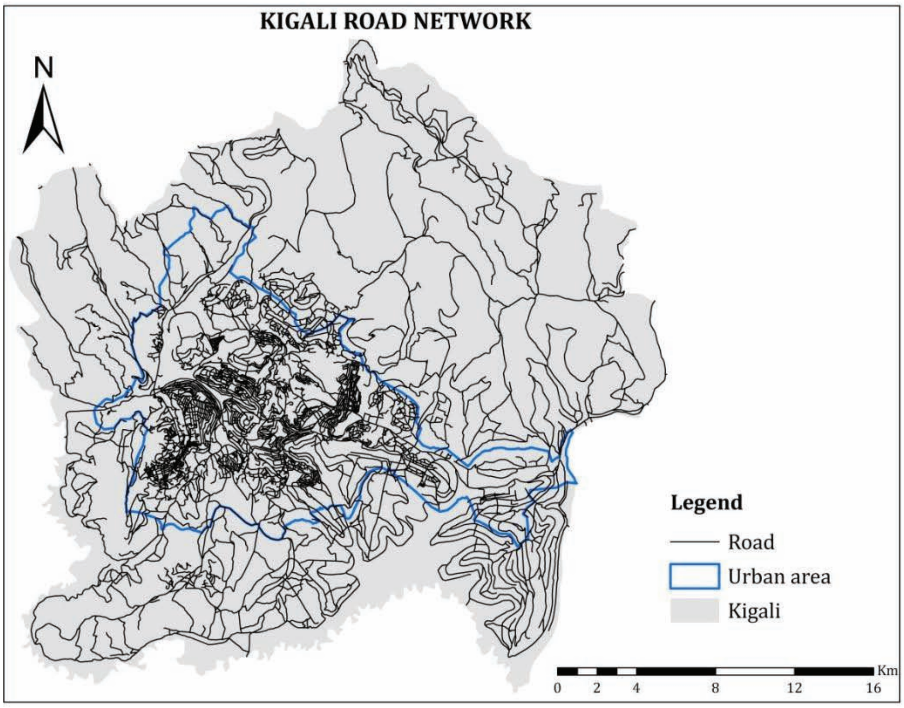


Figure 10: Kigali road network

3.5.2. Modal share

As from the figures depicted from the 2004 traffic counts by Japan experts, the total number of vehicles moving within Kigali was 58,700 trips consisting 46.6% by cars, 29.4% by buses and 24.0% by trucks(Japan Engineering Consultants, 2004). Traffic volumes from Monday to Friday are almost the same. Comparatively to normal working days, traffic volumes during Sundays and Saturdays are about only 50% and 75% respectively. Identical, traffic volume at the midnight from 0:00hrs to 5:00hrs is relatively very small (MININFRA, 2011).

3.5.3. Institutional organization of public transport

There is no independent urban transport regulatory authority in the City of Kigali. Different institutions intervene in the course of regulation of public transport. The deliverance of operating license is ensured by Rwanda Utilities Regulatory Agency, RURA. The routes network expansions are made on an incremental basis with changes generally instigated by operators rather than by the government authorities, since there is no systematic bus route planning based on a cycle of monitoring, planning, and implementing adjustments to the routes network. This lack of regulatory framework for public transport operation and management appears as a hurdle for the development of public transport in Kigali.

Among the institutions intervening in public transport sector, there are two main transport regulatory agencies, namely RURA and National Police. The duties of other intervening institutions such as MININFRA, RTDA, NRF, Kigali City, and Kigali Districts are herewith summarized.

- **RURA, Rwanda Utilities Regulatory Agency**

In regards to the road transport, the key issues of RURA is to ensure that it is performing well, that the Government regulatory policy toward it is appropriate and effective, that the environmental concerns are being duly addressed, and that benefit from investment in improved road will be passed on to road users and responsive road transport services.
It also handles matters specific to urban transport, and covers how to assess road transport performance and ways of tackling important issues affecting the development of trucking and passenger public transport services(RURA, 2011).

- **RNP, Rwanda National Police**

RNP is responsible to ensure road traffic and road safety regulation as part of its regulatory portfolio.

- **Kigali City**

KCC is responsible for developing a master plan which includes, among other matters, also the road and street system; the planning, programming, management and supervision of maintenance works for the City of Kigali road network. In addition, Districts and City of Kigali are also responsible of development, operation and management of the transport system of the Districts and Kigali City respectively.

- **RTDA, Rwanda Transport Development Agency**

The core functional responsibility of RTDA is to plan, develop, manage and control the national road network, the airport infrastructure, inland waterways infrastructure and the railway initiatives

- **NRF, National Road Fund**

The primary responsibilities of the National Road Fund are to effectively collect manage and disburse funds earmarked for road maintenance and other construction works roads in Rwanda as determined by Presidential Order.

- **MININFRA, Ministry of Infrastructure**

The Ministry of Infrastructure is responsible for transport policy and strategy coordination, and RTDA and RNF work under its auspices.

3.5.4. Kigali public transport tariffs review

The set of public transport fare is ensured by RURA in consultation with different government agencies, representatives of Consumer Associations and bus companies' authorities. The economic affairs department of RURA is specifically in charge of gathering all stakeholders for tariff review, among them:

- A representative of MININFRA, Ministry of Infrastructure
- A representative of MINICOM, Ministry of Commerce
- A representative of MINALOC, Ministry of local government
- A representative of MINECOFIN, Ministry of Finance
- A representative of RDB, Rwanda Development Board
- A representative of RTDA, Rwanda Transport Development Agency
- A representative of PSF, Private Sector Federation
- A representative of Kigali City
- A representative of Traffic Police
- All public transport companies representatives
- Representatives of Consumer Associations set by MINICOM and MINALOC

The establishment of bus tariff is based on the cost of operating cost of bus per a travelled kilometre. The following table describes the items considered to estimate the operating cost of buses.

Table 10: Kigali public transport tariff model

No	Item
1	Bus depreciation
2	Bus insurance
3	Various taxes and regulatory fees
4	Salary for driver
5	Salary for driver's assistant
6	Technical control fee
7	Tyre cost
8	Bus company personnel fees
9	Parking fee
10	Washing fee
11	Maintenance and repair
12	Communication fee
13	Security guard fee
14	Bank interests
15	Office stationary
16	Fuel cost/month
Total Operating cost	
Margin (10%)	
Monthly revenue requirement	
Cost per km	
Cost/km/pers	

3.6. Overview of the current state of public transport in Kigali

Public transport within Kigali is dominated by taxi minibus and buses, with a number of different routes, connecting the main hubs of the city. There is no specific operation schedule, these services wait to fill up before setting off from the terminus, then pick up and drop off frequently en route (Kigali City, 2011d). The bus service is totally fragmented among numerous individual operators. These individual operators with buses mainly ranging from 18-seat capacity to 28-seats capacity are under the control of ATRACO, which is the association of individual operators. In addition to the ATRACO, private companies are being attracted to invest in public transport service, among them we can enumerate:

- **Kigali Bus Service, KBS**, with buses ranging from 28-seats capacity to 80-seat capacity;
- **International-express Ltd**, with buses ranging from 24-seat capacity to 36-seat capacity;
- **Prince express**, with buses ranging from 24-seat capacity to 28-seat capacity;
- **Royal express**, with buses ranging from 18-seat capacity to 28-seat capacity

Approximately 75% of buses leave always full and are just as likely to leave full from the remote terminus as the central terminus, and a relatively proportion of 35% of passengers required a second bus to complete their journey.

The actual fare of PT in Kgali is fixed at 20 Rwf/km (USD $0.036/km), but it normally ranges between 150 RwF (USD $0.27) to 250 Rwf (USD $0.45) depending to the route travelled, since passengers pay according to the route travelled not according to kilometres travelled. The behaviour of bus drivers and conductors are relatively honest. With a continuous monitoring of traffic police, bus driving is relatively good and the cases of stealing of fare money are rare.

During waiting times, passengers form orderly queues, and board buses in the sequence in which they arrived, thus pick-pocketing circumstances are infrequent. Except a number of cases during nights, buses do not load more than the designed seating capacity. The hygiene of buses is relatively fair, but some minibuses are in relatively decrepit state which would induce a low comfort level.

Based on fieldwork observation, high demand and small buses do produce high waiting times at all terminals and tend to contribute to the increase in traffic congestion, which is a considerable disadvantage of minibus operations. Bus services do normally start between 5:30 and 6:00 in the morning and operate till between 21:00 and 21:30, but some routes are out of service even before this time.

In terms of public transport infrastructure, the route network consists of the main circular road in the CBD and radial roads connecting the main hubs in the city. Traffic signals are rare, and traffic police operate at the conflicting points generally simulating an uncoordinated signal cycle. Buses mostly operate on the paved roads.

3.7. Concluding remarks

The description of the study area is crucial to determine the operating environment of public transport system being subjected to be assessed. It is well-known that the geographic settings and socio-economic background within which a public transport system operates can strongly affect its performance and effectiveness. This chapter called briefly attention to different characteristics of Kigali. It illustrated different features reflecting operational environment of public transport in Kigali.

4. RESEARCH METHODOLOGY

4.1. Introduction

This chapter intends to describe methods and techniques used to respond to the objectives of this research. It outlines the approaches used to collect data and analyse the collected data, and the overall assessment adopted to determine the performance of public transport in Kigali.

Table 11 presents the overall GIS-based methodological framework developed. It consists of steps followed to respond to the objectives of this research.

Table 11: Methodological framework

Steps	Conceptual method	Rationale
Step 1	Data collection	To design a fieldwork methodological plan in order to acquire primary and secondary data
Step 2	Data analysis	To develop a GIS model in order to assess the public transport system, based on adopted performance indicators
Step 3	Estimation of potential transit demand	To define sequential stages followed to estimate the potential transit demand
Step 4	Development of the overall assessment framework	To define the concept used in order to quantify public transport service availability in a manner that accounts for both spatial and temporal aspects of service supply

4.2. Data Collection

A fieldwork methodological plan was designed consisting of three parts, namely pre-fieldwork, fieldwork and post-fieldwork. The first two parts are detailed in this data collection section, while the post-fieldwork is described in data analysis section.

4.2.1. Pre-field work stage

During this stage, we identified the performance indicators, data required and materials needed through literature review, so as to perform the assessment of public transport system. After identifying the data required, a survey methodology plan was designed to ease the data collection during the limited fieldwork period. Figure 11 illustrates the core data acquisition and preparation procedure.

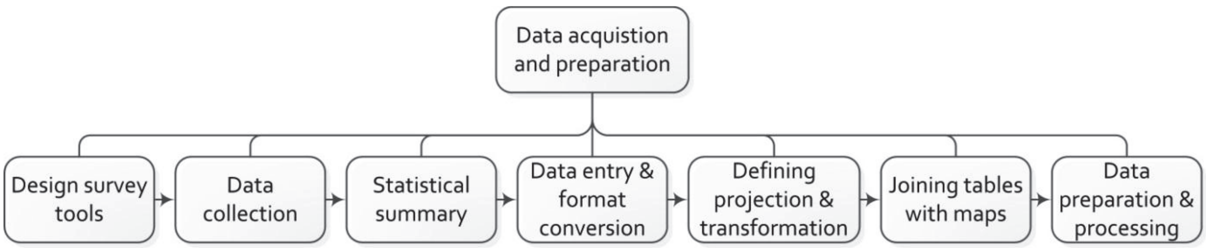


Figure 11: Data processing chart

A preliminary arrangement was established before going on fieldwork by contacting at least one key person at each institution which was intended to be visited during the fieldwork.

The primary data were mainly consisted of digitization of bus stops and recording dispatched buses per route to acquire offered service capacity by public transport in Kigali. The recording of dispatched buses per route requires intervention of surveyors to assist in recording; a logistic plan and the format of the recording form were then made to facilitate this task. Finally, we estimated the cost of the fieldwork and established a detailed fieldwork schedule.

4.2.2. Fieldwork stage

The activities planned in order to collect the data identified during the pre-fieldwork stage were performed during the fieldwork period. This consisted of collecting data from primary sources and secondary sources. The activities were carried out as follow:

1. Getting a permission to conduct a survey from Kigali City
2. Informing the traffic police about the survey
3. Meeting RTDA, RURA, NLC and Kigali City authorities
4. Meeting bus companies' authorities
5. Printing of bus recording forms
6. Training surveyors
7. Conducting a pilot survey
8. Recording of dispatched bus per route
9. Digitizing of all bus stops in Kigali city using a GPS
10. Reconnaissance of prime locations and activities

The meeting of different authorities in charge of public transport and bus companies' authorities helped to understand the operating environment of public transport in Kigali and recognize the operating routes, which facilitated the digitization of bus stops and deployment of surveyors to record dispatched buses at each route. Kigali has in total 28 bus routes.

Afterward, a pilot survey was carried out to validate the logistic plan of the survey process. From the pilot survey which occurred in the afternoon, we got insight of how many forms will be required to record the dispatched buses, and strategic points in which surveyors must be positioned to record effectively the arrival and departure buses at the same time.

- **Logistic plan**

The survey was mainly conducted by 8 surveyors per day. To ensure the quality and validity of data, a surveyor to be recruited was supposed to have at least a high school certificate. Watches were purchased for surveyors to facilitate the synchronization of time.

In addition, since the work had to start so earlier in the morning, a full hour break was guaranteed in the morning, and an hour and 15 minutes break was guaranteed in the afternoon. Therefore, 2 additional surveyors were hired to record dispatched buses during break times, which make a total of 10 surveyors per day. Among the 10 surveyors, every surveyor had at least one day to occupy the position of the replacement (X5 or Y5) during the 7 days of the survey. Table 12 illustrates the logistic plan.

Table 12: Position of the surveyors at the terminal (Daily timetable)

Break time	X5/Y5	X1/Y1	X2/Y2	X3/Y3	X4/Y4
1h00	09h00-10h00				
1h00	10h30-11h30				
1h00	12h00-13h00				
1h00	13h30-14h30				
1h15	15h30-16h45				
1h15	17h15-18h30				
1h15	19h00-20h15				
1h15	20h45-22h00				

Terminology:
X: a terminal (arrival or departure);
Y: the second terminal (arrival for departure from X and departure for arrival X);
1, 2, 3, 4 : fixed routes in a day;
5: location of the replacement

- **Recording of dispatched buses per route**

The recording of busses in service used to start at 06h00 in the morning until around 21h30, not till 22h00 as it was planned during the pre-fieldwork stage since most routes were out of service during that time. Bus traffic volume during working days was considered almost the same in all routes; therefore the recording was scheduled only in working days.

Everyday 2 surveyors were assigned to record dispatched buses at a route, one at a terminal and another at a second terminal, both to record the arrival time and seating capacity of arriving buses, and record as well the departure time and seating capacity of leaving buses from that terminal. Doing so, we managed to record data from four routes per day, and this task lasted seven days since Kigali has 28 public transport routes. Figure 12 illustrates the attributes of the bus recording forms used in the fieldwork.

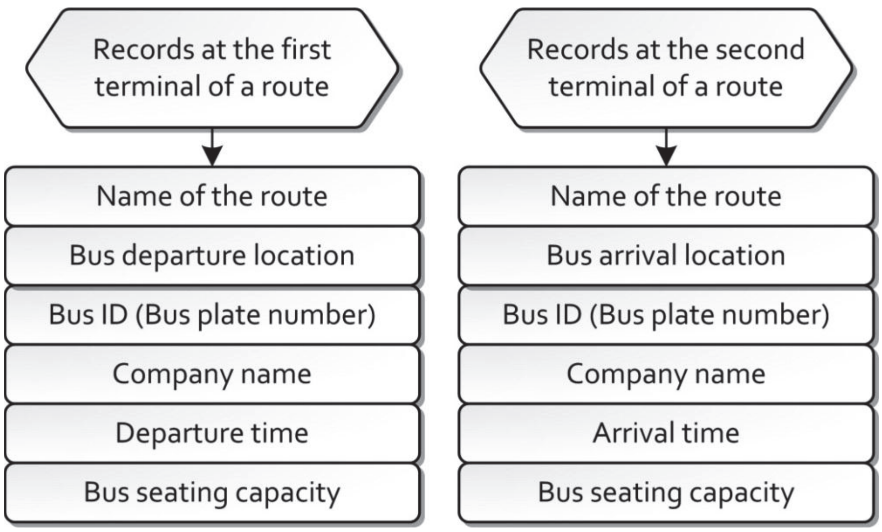


Figure 12: Attributes of bus recording forms

- **Collected data**

The primary data collected consists of all bus stops in Kigali city, and recording of all buses in service at each route, their departure/arrival time and their seating capacity. The reports and digital data collected from the secondary sources are described in Table 13.

Table 13: Data collected from secondary source

No.	Data	Format	Source	Comment
1	Aerial orthophoto images of Kigali city taken in 2009	Orthophoto image of 25 cm resolution	NLC, National Land Centre	-
2	Demographic data aggregated at cell level	Excel tables	Statistic bureaux of Kigali Districts	-
3	Kigali Districts Baseline	PDF document	NISR, National Institute of Statistics of Rwanda	Overview of socio-economic characteristics
4	Kigali cells' boundaries	Shapefile	Kigali City	-
5	Kigali road network	Shapefile	Kigali City	-
6	Kigali contours	Shapefile	ITC	-
7	Kigali public transport routes	Word document	RURA	-
8	Licensed companies for public transport services	Word document	RURA	-
9	Kigali public transport tariff model	PPT document	RURA	-
10	Public transport licensing guidelines	PDF document	RURA	The document is in local language, Kinyarwanda
11	Kigali Master Plan	PDF document	Kigali City	-
12	The Study for Improvement of Urban Transport in Kigali City, Final Report	PDF document	Kigali City	-

4.3. Data Analysis

4.3.1. Data preparation

This section describes the process of converting data into a form that is appropriate for Kigali public transport model. This task includes the construction of bus route network, data entry and verification, joining collected alpha-numeric data with shapefiles to construct maps, and defining coordinate and projection of the shapefiles so as to get data suitable for spatial and statistical analysis.

- **Kigali public transport network construction**

The recorded GPS points of bus stops with their XY points in Excel sheets, along the real public transport routes was converted into shapefiles and labelled. A public transport route was made by joining the bus stops, and the digitization was made by following the track of the real road from the orthophoto image of 25 cm at 1/2500 scale. A segment of the bus route is consisted of joining intersection points of bus routes in order to allow the overlap of segments of different routes passing through the same road.

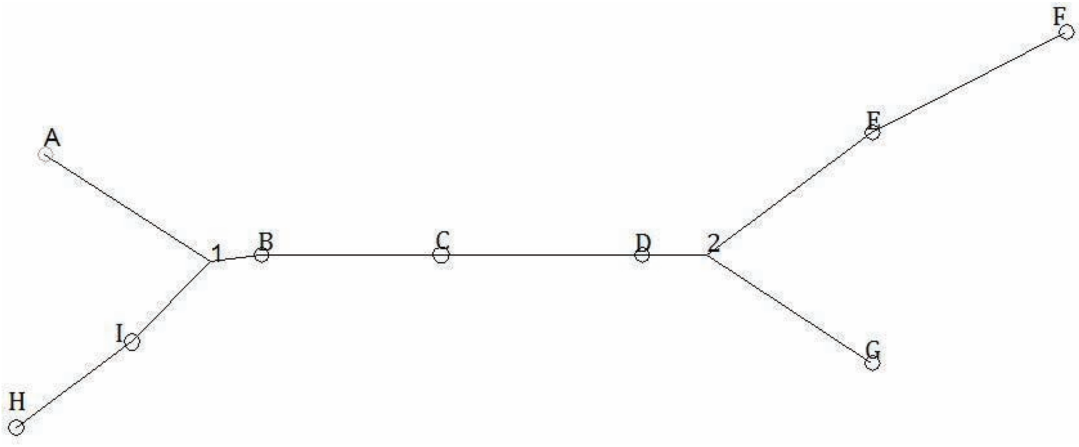


Figure 13: Illustration of bus route network construction

Terminology:
A,B,C,D,E,F,G,H,I: bus stops
1,2: roads intersection points
A1, H1, 12, 2F, 2G: road segments
AF, AG, AH, HF, HG, FG: bus routes

- **Offered bus service capacity**

The offered bus service capacity is determined by the seating capacity of buses operated along the route per day, their frequencies and travel speed. The hard-copies of recorded buses from both terminals of a route were converted into digital format by writing down the data in excel sheets. The depicted information is illustrated in the Table 14, with route length generated from route network constructed in a GIS platform.

Table 14: Attributes of digital recording form

Route ID	Bus ID	Departure time	Arrival time	Seating capacity	Route length	Travel Time	Operating speed	Frequency	Headway

4.3.2. Bus route-system

After constructing the bus route network and defining attribute of bus routes, we created a bus route-system. A route-system is a collection of routes with a common system of measurement. A route can be composed of inter-connected sections defined by relative positions along road segments (arcs). Similarly, a road segment or arc can also accommodate many routes. This results in a many-to-many relationship, which cannot be handled by a typical arc node model. To cope with large variety of dynamic data structures associated with route-system, transport planning relies on dynamic segmentation model.

A dynamic segmentation model has ability to link route attributes to its specific linear features and preserve the topological consistency of the feature (Northwest GIS Services, 2012; Zhengdong & Masser, 2002). It is mainly composed by three tables:

- Sections attributes table (SEC): sections denote arcs in coverage, and SEC enables to link a section to a particular route.
- Routes attributes table (RAT): route is defined as a group of sections belonging to a specific real world route, and RAT contains data associated to the real world route.
- Arcs attributes table (AAT): it encompasses attributes of the road segments (linear features) in a spatial database.

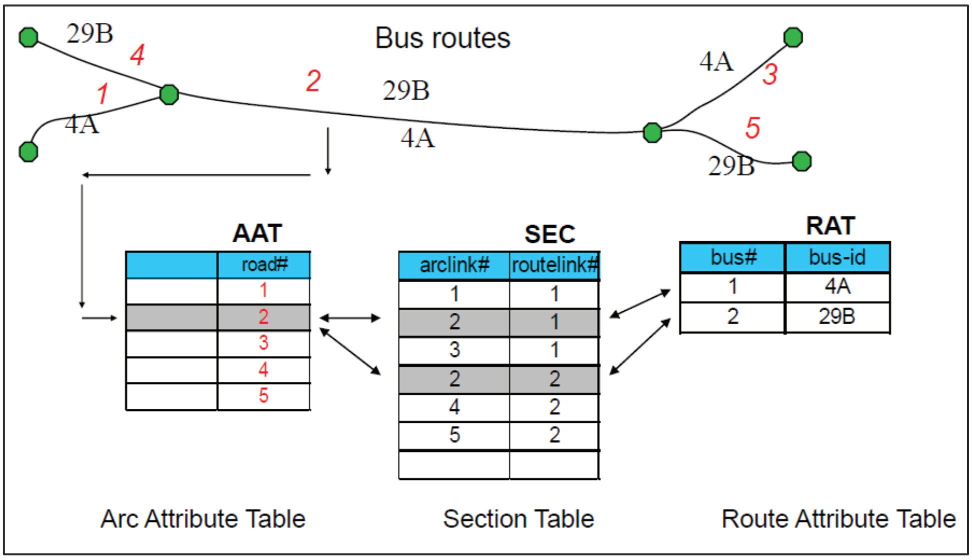


Figure 14: Example of a GIS-based dynamic segmentation model

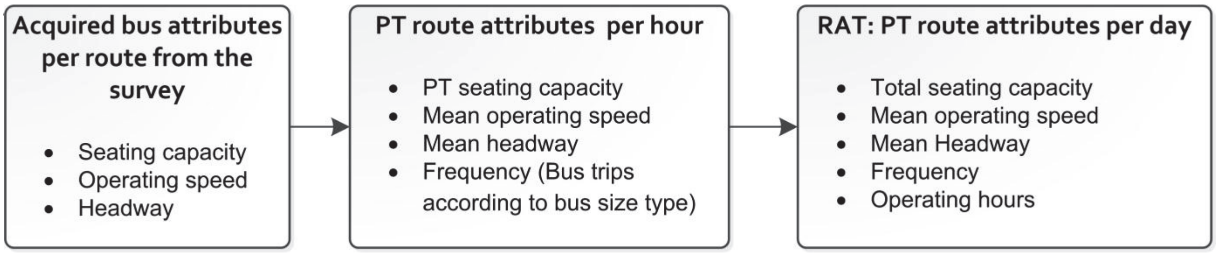


Figure 15: Creation of RAT

4.3.3. Service performance evaluation

The evaluation of public transport service performance was performed in two stages. In the first stage, we presented the situational analysis based on route performance indicators and service capacity performance indicators defined in Table 3 and Table 4. The situational analysis is based on the score of each individual performance indicator. Table 15 indicates the adopted indicators, and Figure 16 presents the data analysis process for situational analysis.

In the second stage, we develop an overall performance of public transport service based on the aggregation and weighting of individual performance indicators. The development of the overall assessment framework is presented in section 5 of this chapter.

Table 15: Service performance indicators

Route network performance indicators	Service capacity performance indicators
Service coverage	Seating capacity
Network density	Observed frequency/headway
Bus stop spacing	Service span
Route overlap	Operating speed

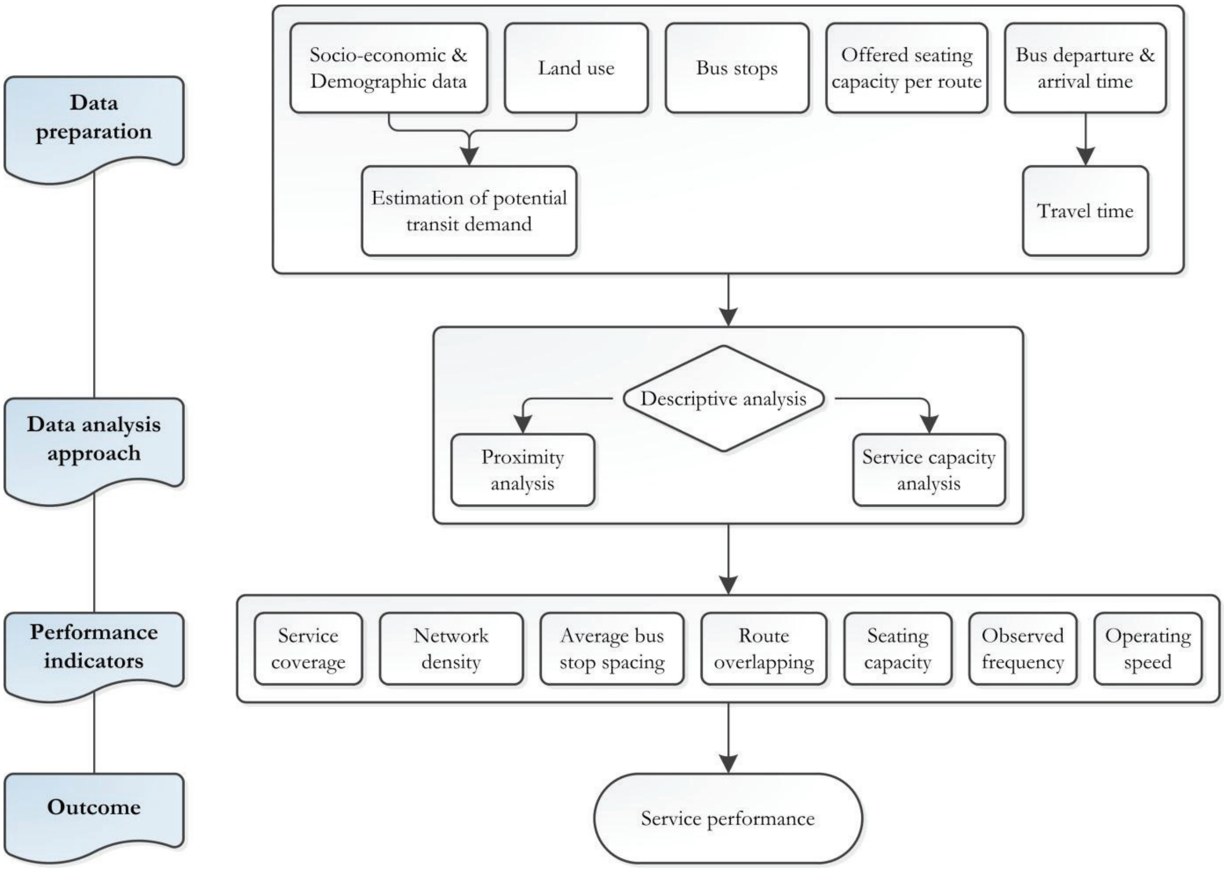


Figure 16: Data analysis process

4.4. Estimation of potential transit demand

4.4.1. The four-stage transport model

The transport planning process is usually carried in a number of sequential stages, in what has been called four-stage classic transport model.

The approach starts with considering a network and zoning system, called a traffic analysis zone (TAZ), and the collection of data. These data are used to estimate a model of the total number of trips generated by or attracted to each zone: ***Trip generation***. The next stage is concerned with the estimation of the number of trips per unit time which will be made under certain circumstances between each pair of zones in an area to which the process is being applied: ***Trip distribution***. The following stage is usually the modelling of the choice of mode to be used for making the trip: ***Modal split***. The last stage is to provide an estimate of the amount of traffic which will use each part of a transport network under certain conditions: ***Trip assignment*** (Suzanne P, 1976; Zuidgeest & van Maarseveen, 2011).

This four-stage transport model is based on gravity model concept; the estimated pattern of trips depends on the trip magnitude between each pair of zones, and is inversely proportional to the costs of travel between the various pairs of zones.

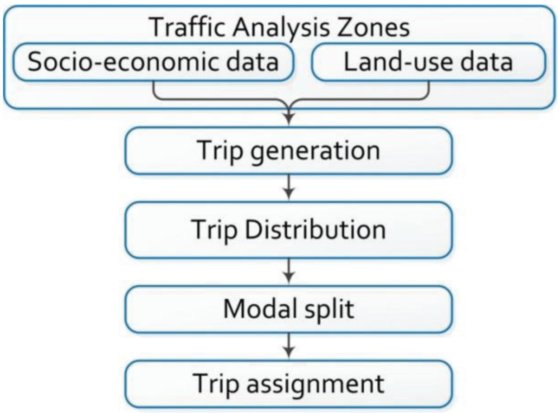


Figure 17: The classic four-stage transport model

4.4.2. Trip generation

The undertaken research is solely interested on the estimation of potential trips for public transport in Kigali. Based on a 24 hours survey carried out by Japan Engineering Consultants in 2004, the vehicle origin-destination (OD) in Kigali was 58,700 trips consisted of 46.6% by private cars, 29.4% by buses and 24% by trucks (Japan Engineering Consultants, 2004). According to this survey, the average numbers of passengers carried by private car, bus, and truck, was respectively 2.6, 15.4 and 3. These figures provide the generated trips for public transport in 2004. Due to the lack of socio-economic data, we assumed that the production of trips per cell, which is considered as a TAZ, being proportional to the population of that cell.

According to (White, 2002), a trip rate per capita may be used for forecasting public transport demand in a typical urban area. In line with this respect, we assumed that the trip rate per capita in 2004 will apply in 2011, and hence total volume changes only in response to population growth.

Likewise, the estimation of attracted trips per TAZ was affected by the lack of socio-economic data, and the fact that Kigali has no land use map ever produced. We assumed that the trip attraction per cell is proportional to the population density. This was supported by the fact that 60% of Kigali population work in informal sector, and the fact that Kigali is comprised by unplanned and squalid settlements resulted from the rapid urbanization, with more than 80% of the population living in informal neighbourhoods (OZ Architecture et al., 2007; The World Bank, 2011a). Moreover, the population density is an overall measure of intensity of activities, including residential, employment, and all other activities, assuming that they are generally closely correlated(Vuchic, 2005).

Finally, the trip attraction is modified by a matching factor to ensure balance between the total number of trips produced and attracted in the city.

To rationalize the trip assignment to the network, the trips generated at each TAZ were overlaid with small hexagons of 400 metre edge length, in order to arrive at trip productions and attractions at spatially disaggregated level.

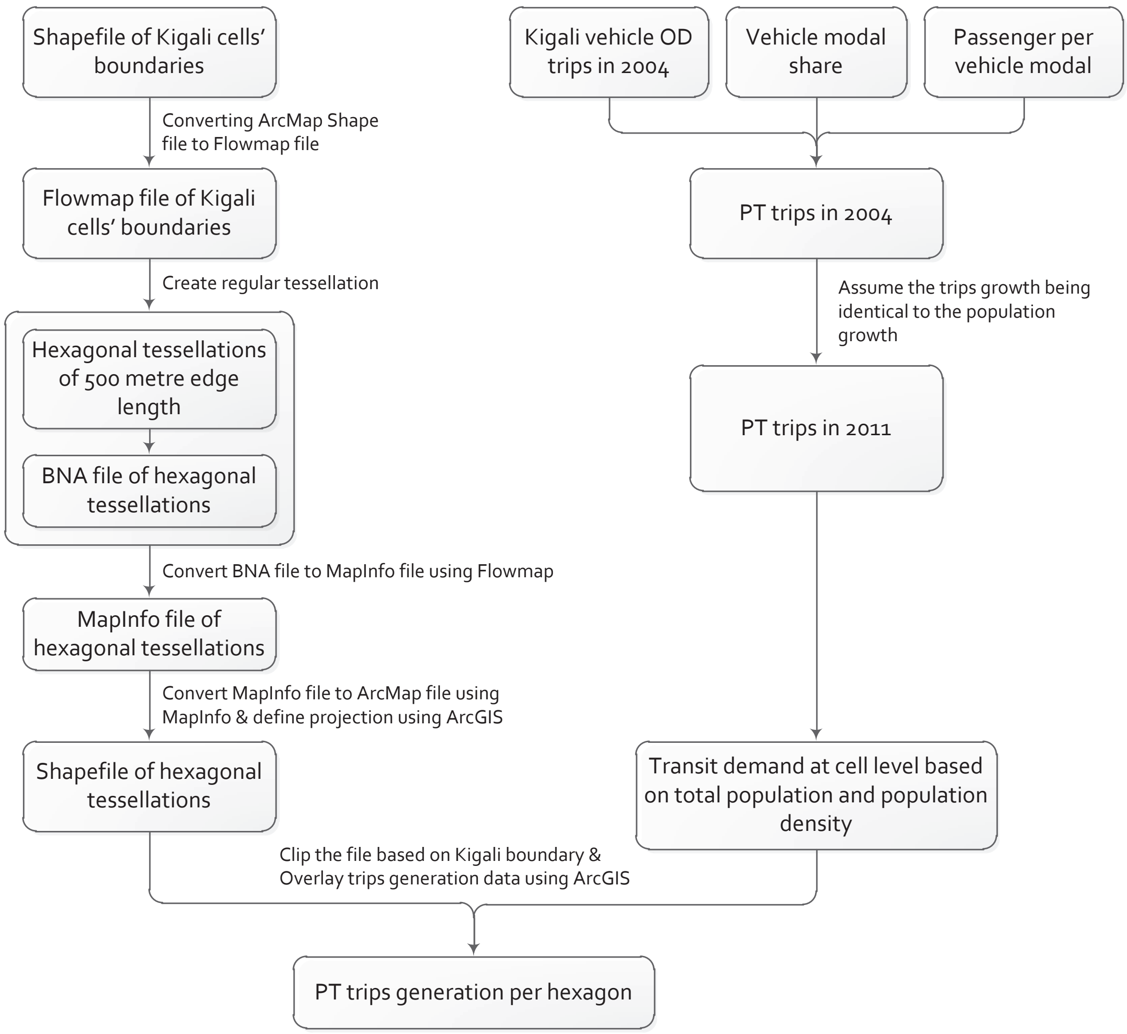


Figure 18: Stepwise flowchart of assignment of the trips to hexagons

4.4.3. Trip distribution

The allocation of trips to their particular destinations is done through a doubly constrained gravity model with exponential cost function. The doubly constrained model consists of three principles:

- The sum of the estimated number of trips from every origin must be equal to a preset number per origin.
- The sum of the estimated number of trips to every destination must be equal to a preset number per destination.
- The number of trips from every origin to any destination is inversely related to the cost between them.

The calibration of the doubly constrained gravity model was based on the mean trip length (MTL). The MTL provides insight into the distance people are willing to travel for a specific purpose (Breukelman,

Brink, jong, & Floor, 2009). This MTL describes the attraction value, and is used to calculate the distance decay function.
Normally the MTL is deducted from observed trips during the past. However, in case there is no data on observed trips in past available, Flowmap software can generate and calculate a number of mounting values for the distance decay parameter (Beta value) in order to determine fair values for the MTL and/or the distance decay parameter (Breukelman et al., 2009).

The distance decay function and the mean trip length (MTL) are defined by the following formula:

$$f(c_{ij}) = \exp(-\beta c_{ij}) \quad with\ \beta > 0$$

$$MTL = (\sum_i \sum_j T_{ij} C_{ij}) / (\sum_i \sum_j T_{ij})$$

With:

$$T_{ij} = A_i B_j O_i D_j f(C_{ij}) \qquad A_i = 1/(\sum_j B_j D_j f(C_{ij}) \qquad B_j = 1/(\sum_i A_i O_i f(C_{ij})$$

Where:
T_{ij} = the estimated number of trips between origin i and destination j
C_{ij} = the distance travel time between origin i and destination j
A_i= the balancing factor for origin i
B_j= the balancing factor foe destination j
O_i= the constraint value for origin i
D_j= the constraint value for destination i
β = the distance decay parameter

4.4.4. Modal split and trip assignment

The model considered the trips uniquely generated for public transport mode. Hence there is no modal split stage applied in our modelling process. This section only explains the steps followed to assign the trips to public transport network.
In earlier stages while constructing the bus route network as shown in Figure 13, we constructed route segments by joining intersection points of bus routes in order to later allow overlaps of different routes. This resulted in 78 segments in total.

However, since we had to assign the trips to network based on node in Flowmap software, we split the bus routes by bus stops in ArcGIS. This resulted in 228 small segments, named route splits. These route splits were converted into Flowmap file to represent the public transport network. The idea is simply to allow a more accurate assignment of the flow over the network. In this respect, a node in Flowmap is likely to represent the real bus stop.

4.5. Overall assessment framework

4.5.1. Overall performance development concept

The development of public transport performance measure is primarily based on underlying goals and objectives (Pratt & Lomax, 1996), and the mathematical structure of the measures should be underlined on them as well. According to (Kittelson et al., 2003), the development of public transport performance measurement should take into consideration the following facts:

1. The number of measures to be reported: too many will overwhelm users, while too few may not present a complete picture.
2. The amount of detail to be provided: general measures will be easier to calculate and present, but more detailed measures will incorporate a greater number of factors influencing performance.
3. The kinds of comparison that are desired to be made: will performance be evaluated only internally or compared with other agencies?
4. The intended audience: some audiences will be more familiar with public transport services and concepts than others

The trade-off among the underlined facts have been led to the use of one or more types of the measures in performance evaluation (Bhat et al., 2006; Kittelson et al., 2003), as described below:

1. <u>Individual measures</u>: they usually reflect a single attribute of a public transport system; they are intuitive and easy to compute

2. <u>Ratios</u>: they are developed by dividing one individual measure by another; contrary to individual measures, ratios measures are normalized but they suffer from the problem of describing only a single aspect of system performance.

3. <u>Index measures</u>: they simplify the reporting of potentially complex measures from several other performance measures in an equation to produce a single output measure, which overcome the problem of describing a single aspect of system performance. The drawback of index measures are that they cannot be directly measured in the field, may not be particularly intuitive, and may mask significant changes in their constituting measures.

4. <u>Level of service (LOS)</u>: they were developed as a means of simplifying the presentation of potentially complex measures and, particularly, to help interpret how travelers perceive conditions represented by a particular performance measure value. As well as index measures, LOS measures provide a simple way to present evaluation results to the public and to decision makers, but they mask performance changes and trends occurring in the underlying measures.

The findings are that many numerous public transport performance measures have developed, and the amount of effort required to calculate them varies considerably depending on the aims envisaged. It is worth then to primarily categorize performance measures based on their principal aims (Pratt & Lomax, 1996), even though their definitions are subject to interpretation since they often overlap each other. Figure 19 summarizes the concept of the overall performance development.

Although it is not a straightforward task to categorize performance measures, (Kittelson et al., 2003) identifies eight categories and the subcategories, in that along, passengers, communities and operators viewpoints are addressed as shown in Table 16.

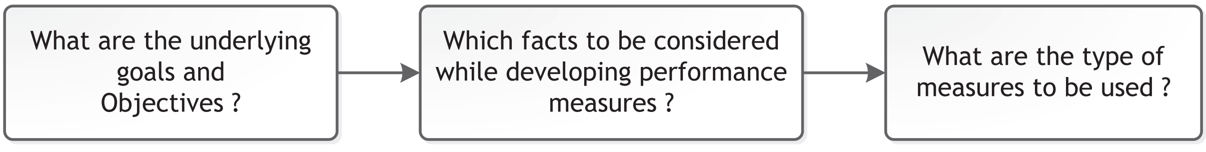


Figure 19: Concept of the overall performance development

Table 16: Goal/Objective-based categories to organise public transport performance measures

Categories	Subcategories
Service availability	Spatial availability Temporal availability Para-Transit availability Capacity availability
Service delivery	Reliability Customer service Passenger loading Goal accomplishment
Community impact of public transport	Mobility Outcomes Environment
Travel time	Time Speed
Safety and security	
Maintenance and construction	
Economic	Utilization Efficiency Effectiveness Administration
Capacity	

Source (Bhat et al., 2005)

According to (Bhat et al., 2005), these categories are by no means mutually exclusive and, hence, represent only one way of classifying the common goals and objectives of public transport planning and evaluation process. For example, *travel time* measures, which assess "how long it takes to make a trip by public transport" may also be considered as an indicator of *mobility*, which is defined as "the ease of traveling between locations within a community." Also, measures of *capacity* are candidates for measuring *service availability* and *service delivery*.

4.5.2. Adopted indicators for overall performance evaluation

In consideration of the overall performance development concept, as summarized in Figure 19, an assessment structure was developed. The belief is that if the distances to access a service is too great at either the trip origin or destination, then public transport is unlikely to be utilized as a mode of travel (Murray et al., 1998). Yet, the temporal side of public transport is crucial, considering that a service within walking distances is not considered as available if times of waiting are more than what passengers can tolerate (Bhat et al., 2006; Polzin et al., 2002). Similarly, if the service is insufficient to satisfy the demand then utilization of the service is also unlikely.

Accordingly, out of 8 individual performance indicators adopted as indicated in Table 15, we identified key performance indicators in order to get a complete picture of public transport service availability. This reflects the theoretical background of the overall assessment. The weighting and aggregation approach of these indicators are presented in Figure 21 of the following sub-section.
Table 17 indicates the adopted indicators for overall performance assessment.

Table 17: Adopted indicators for overall performance assessment

Performance indicators	Dimension
Service coverage	Spatial availability
Headway	Temporal availability
Service span	
Seating capacity	

4.5.3. Service performance assessment structure

Figure 20 describes the analysis structure of the approach undertaken to assess the service performance of public transport system in Kigali. The mathematical formulation of performance measurement, which is basically based on the weightings of individual performance indicators, is herewith explained.

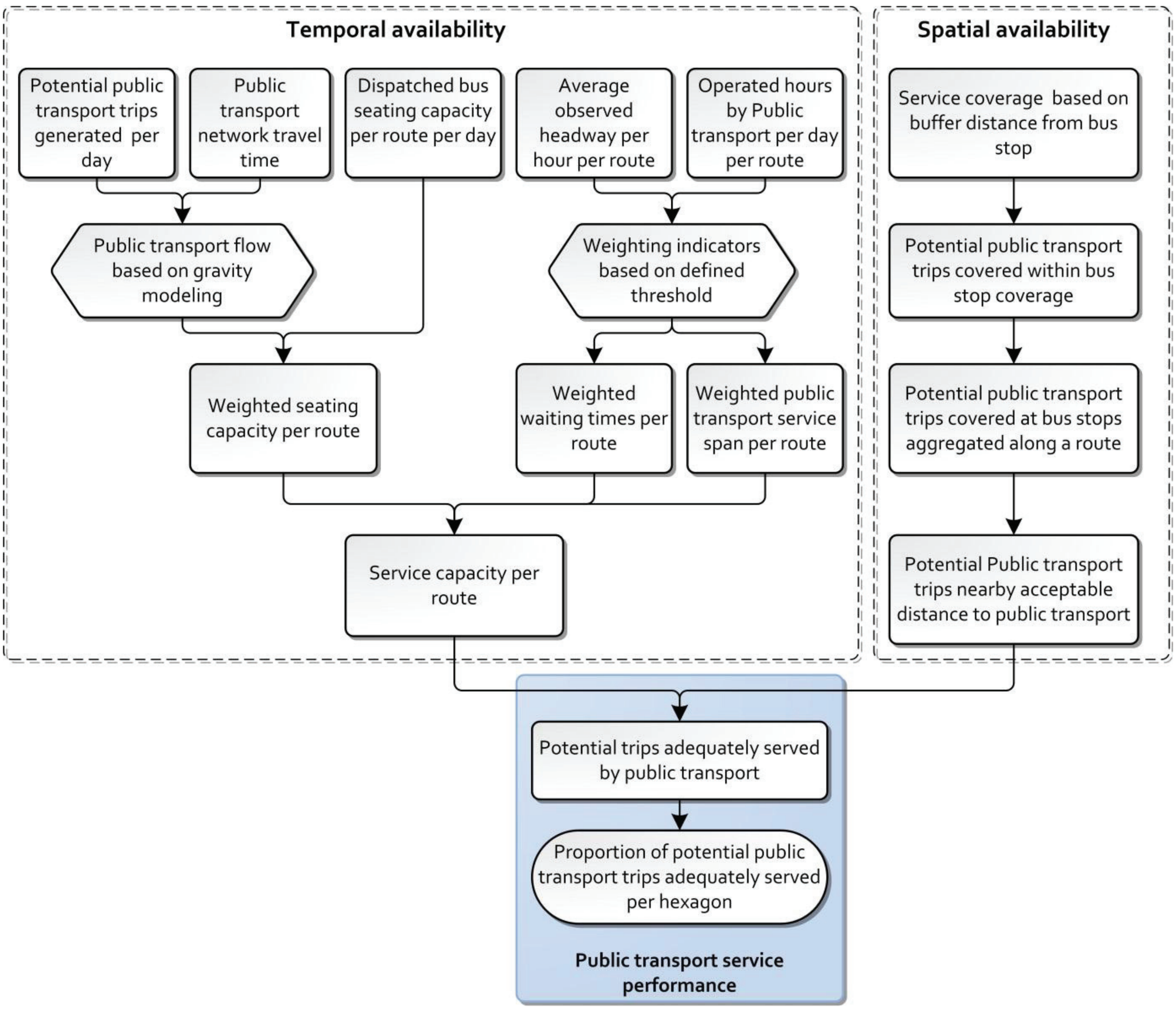


Figure 20: Framework of public transport service availability analysis

This sub-section explains the operationalization (i.e. weighting and aggregation) of key performance indicators identified in above subsection (see Table 17). It is subdivided into two dimensions namely; temporal availability and spatial availability.

The mathematical formulation of performance measurement was adapted from (Bhat et al., 2006; Kittelson et al., 2003; Mavoa et al., 2012; Polzin et al., 2002).

Figure 21 illustrates the GIS-based model used to develop a system-level performance measurement; and the mathematical structure of the measures follows this illustration.

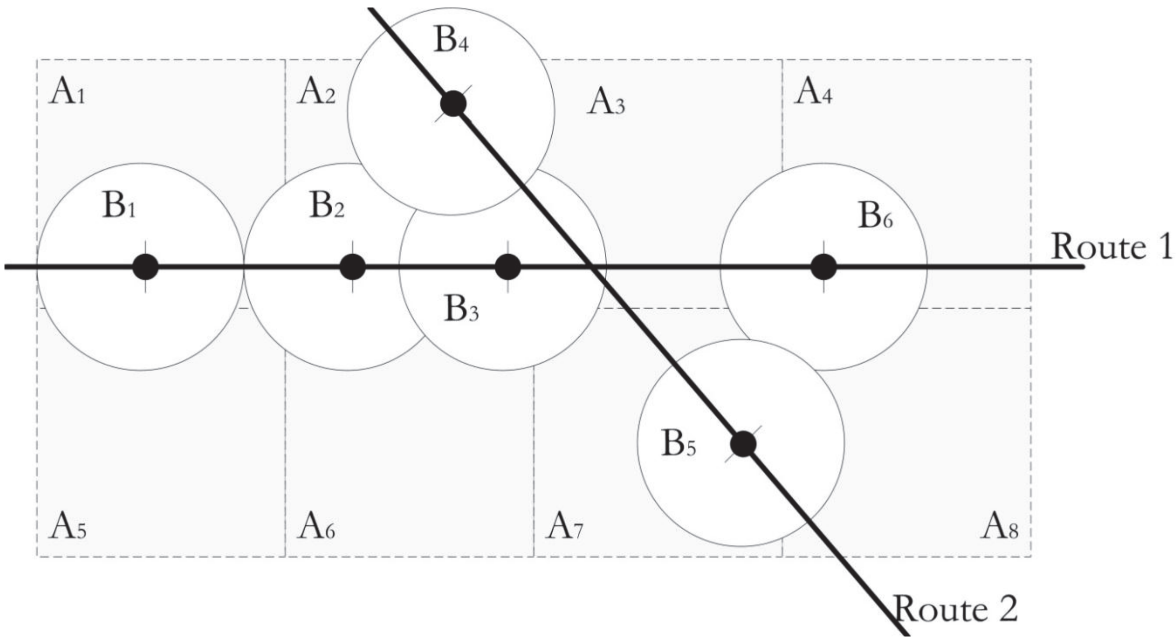


Figure 21: Illustration of the GIS-based analysis structure

- **Assessment of temporal availability of public transport service**

In the preceding section (section 4 of chapter 4), we defined sequential stages followed to estimate the potential transit demand. Among the outputs of that estimation is the trips produced and attracted at each hexagon, and the amounts of trips travelled along a particular route per day.

The volume of trips per route per day was divided by the seating capacity offered at the subjected route per day, in order to weight the seating capacity per route.

However, public transport mode is unlikely to be a valuable mode of transport in case either the waiting time outstrips a certain threshold or the service span is limited in a certain period of the day. These highlighted reflections guided the weighting of service capacity.

The weighted seating capacity per route *k* is calculated using the following formula:

$$C_k = \frac{N_k}{P_k}$$

where, N_k =total number of bus seats offered on route *k* per day

P_k =potential passengers to travel in route *k* per day.

The weighted waiting times per route *k* per day is calculated using the following formula :

$$W_k = \frac{1}{n}\sum_{i=1}^{n} F_i \quad \text{with} \quad F_i = \frac{H}{H_i}$$

where, n = total operated hours per day

H = acceptable waiting time

H_i = Mean headway per hour

$F_i = 1$ if $H_i \leq H$, considering that from passenger perspective, whether buses are running regularly is more important than whether they are actually running on schedule under the conditions of short frequency (Chen et al., 2009).

The weighted span of public transport service is calculating using the following formula:

$$O_k = \frac{O}{n}$$

where, O = acceptable period during which service should be offered

n = total operated hours per day

Hereafter, the service capacity at a route *k* weighted by the transit demand, with consideration of time in which service is available, is calculated as follow:

$$Q_k = C_k W_k O_k$$

The overlay of trips generated per hexagon and the catchment area of bus stops weighted by their service capacities determines the number of trips which can be served by public transport in that hexagon, based on service capacity of public transport.

- **Assessment of spatial availability of public transport service**

The service coverage here referred as physical access which is the distance that people walk to get to a bus stop is an important factor to define the service availability. The public transport service coverage is constructed using GIS buffering based on the defined threshold from bus stops, since bus stops are the actual locations where passengers access the public transport service (Mavoa et al., 2012). The service buffers are intersected with a hexagon to ascertain the potential public transport trips covered by public transport within the bus stops coverage.

The potential public transport trips covered at a bus stop *i* are calculated considering that a service buffer *i* intersects, either fully or partially, with a number of hexagon *j* ranging from 1 to J hexagons as illustrated by the following formula:

$$B_i = \sum_{j=1}^{J} T_{ij} \quad \text{with} \quad T_{ij} = \frac{A_{ij}}{A_j} T_j$$

where, A_{ij} = area of intersection between the buffer *i* and the hexagon *j*

A_j = total area of the hexagon *j*

T_j = potential public transport trips in hexagon *j*, we assume that the trips are uniformly distribute within the hexagon.

- **Overall assessment of public transport service availability**

The total public transport trips covered at a certain bus stop do not necessarily explain that they are all adequately served. It is worth to determine the potential trips for which the service is available vis-à-vis to the capacity of public transport.

The potential trips than can be adequately served by public transport at a bus stop *i* belonging to the route *k* are determined by the following formula:

$$S_i = B_i Q_k$$

where, B_i = potential public transport trips covered at a bus stop *i*

Q_k = service capacity at a route *k* weighted by the transit demand

Finally, the total trips adequately served within a hexagon are given by the following formula :

$$P_j = \sum_{i=1}^{I} S_{ij} \quad \text{with} \quad S_{ij} = \frac{BA_{ij}}{BA_i} S_i$$

where, BA_{ij} = area of intersection between the hexagon *j* and the buffer *i*

BA_i = total area of the buffer *i*

S_i = potential public transport trips adequately served at the bus stop *i* , we assume that the trips are uniformly distributed within the service buffer.

Conclusively, the proportion of potential public transport trips generated at a hexagon and the total trips which can be adequately served by public transport, would highlight the level of service availability in that particular hexagon.

4.6. Concluding remarks

The methodological framework of this research was presented in this chapter. This consists of the methods, tools and approaches used to collect data and to analyse the collected data. It further presents sequential stages followed to estimate the potential transit demand, and the mathematical structure of the measures used to develop a system-level performance measurement, in order to quantify public transport service availability.

We developed a performance measurement to identify the level of public transport service availability in different locations in Kigali using a spatial unit relatively smaller than a cell[2]. Given that using the spatial administrative unit like a cell, would result in an ecological fallacy rather than giving a reliable picture of service availability. On the other hand, the use of small spatial unit weakens the computation speed during the modelling. In order to maintain a reasonable computation speed and accuracy, a particular zone (i.e. location) of the city was represented by a 400 metres edge hexagon, and thus Kigali built up area was divided into 493 hexagons.

The results of these developments are presented in two chapters, chapter 5 and chapter 6. In chapter 5, a situational analysis is presented, which is based on the performance of individual performance indicator. Later in chapter 6, the overall performance of public transport system is presented, which is based on the aggregation of individual performance indicators.

[2] A cell is the smallest spatial representation of administrative area (i.e. unit) in Kigali

5. SITUATIONAL ANALYSIS

5.1. Introduction

This chapter provides the results of the performance evaluation of adopted performance indicators of public transport service. The situational analysis is based on the score of each individual performance indicator. These indicators are defined in the preceding chapter 2 in Table 3 and Table 4.

5.2. Service coverage

The spatial coverage of public transport is an important factor to measure the ease at which services can be reached at different locations. This gives way to measure spatial equity in service provision, and can be achieved through the use of GIS based modelling approaches. The use of GIS gives a possibility to delineate areas for which public transport demand is covered, and how best to represent potential demand spatially using different technics such as buffering operation(Horner & Murray, 2004).

For example, in buffering operation, two main issues are involved, namely the feature or reference of measurement being either bus stops or routes, and the size of the buffer to define the threshold. Though, bus stops offer a more appropriate basis than routes for estimating service area coverage because stops are the actual locations where public transport users access the system (Bhat et al., 2006).
Buffers may be computed based on a Euclidean distance or based on a network distance measured along a street line to get to the feature. Network distance is likely to be more realistic since it considers a walking distance which people use to reach the public transport feature (Gutierrez & Garc¡a-Palomares, 2008).
In this study, the proximity analysis is based on Euclidean distance due to lack of street lines. However, the rationalization of buffer distances takes into account the topographic characteristics of Kigali as shown in Figure 22.

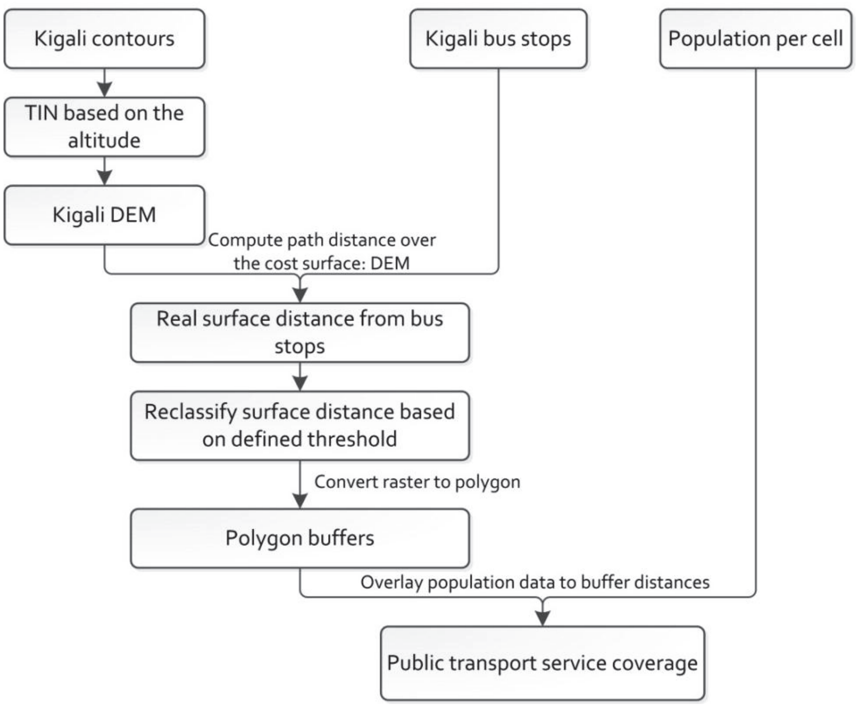


Figure 22: 3D buffer computation

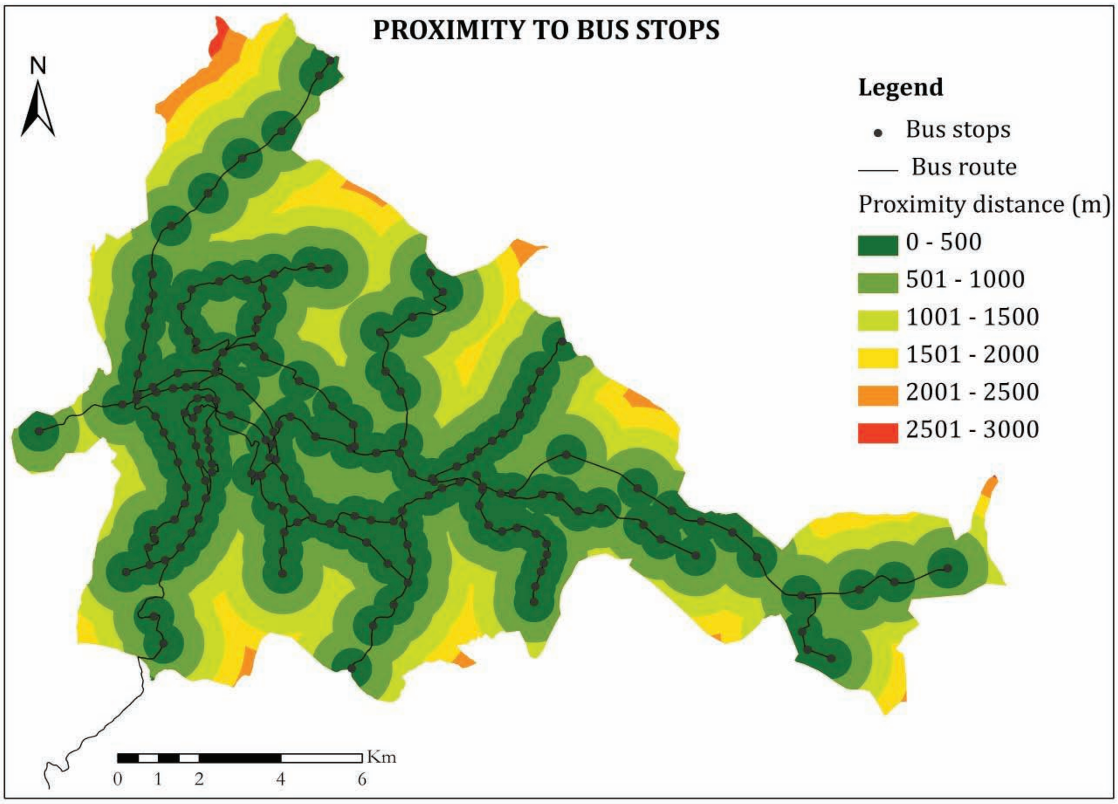


Figure 23: Buffer distances from bus stops

Commonly, public transport planners assume that people are served if they are within 500 m of a bus stop (Armstrong-Wright & Thiriez, 1987; Guihaire & Hao, 2008; White, 2002). However, (Ceder, 2007) suggests that the threshold may go up to 800 m. Along this, (Armstrong-Wright & Thiriez, 1987) indicates that distances in excess of 500 meters may be acceptable in low-density areas, but the maximum distance that passengers have to walk to and from a bus stop should not exceed 1,000 meters.

Table 18: Proximity to bus stops in Kigali

Buffer distance from the bus stops (m)	Served area per defined threshold (%)		Population served per defined threshold (%)	
	All-inclusive Kigali area	Urban area	All-inclusive Kigali Population	Urban population
0 - 500	10.2	42.2	37.7	54.6
500 - 1000	10	33.3	22.7	30.3
1000 - 1500	7.8	16.8	9.8	11
1500 - 2000	6.6	6.2	4.7	3
2000 - 2500	5.9	1.4	3.2	0.8
2500 - 3000	5.6	0.1	2.7	0.3
3000 - 3500	5.3		2.2	
3500 - 4000	5.2		2	
4000 - 4500	5		1.9	
4500 - 5000	4.5		1.6	

Table 19: Cumulative proximity to bus stops in Kigali

Buffer distance from the bus stops (m)	Cumulative served area (%)		Cumulative population served (%)	
	All-inclusive Kigali area	Urban area	All-inclusive Kigali Population	Urban population
0 - 500	10.2	42.2	37.7	54.6
500 - 1000	20.2	75.5	60.4	84.9
1000 - 1500	28	92.3	70.2	96
1500 - 2000	34.6	98.5	74.9	99
2000 - 2500	40.5	99.9	78.1	99.8
2500 - 3000	46.1	100	80.8	100
3000 - 3500	51.4		83	
3500 - 4000	56.5		85	
4000 - 4500	61.5		86.9	
4500 - 5000	66		88.5	

The results (i.e. Table 18 and Figure 24) show that only 54% of Kigali urban population are well-served by current public transport system based upon a set spatial coverage of 500 m. With regards to the urban area coverage, it was found that only 42% of the urban areas are covered by the public transport system. The service coverage percentages fall down considerably in case the computation considers all-inclusive areas of Kigali administrative boundaries. This is because the rural area of Kigali is almost deprived of public transport service. However, these figures go up to 75% for the urban area coverage, and 84% for the urban population, in case a maximum threshold of 1000 m distance is applied as shown in Table 19 and Figure 25.

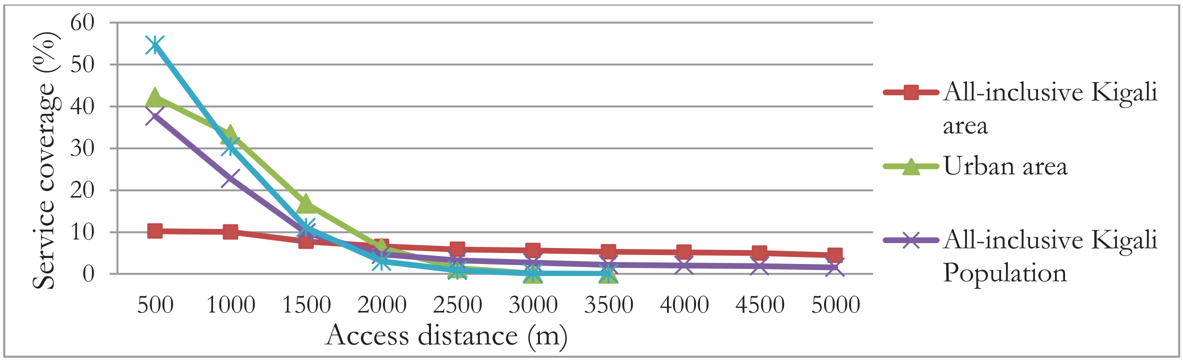


Figure 24: Service coverage per defined distance

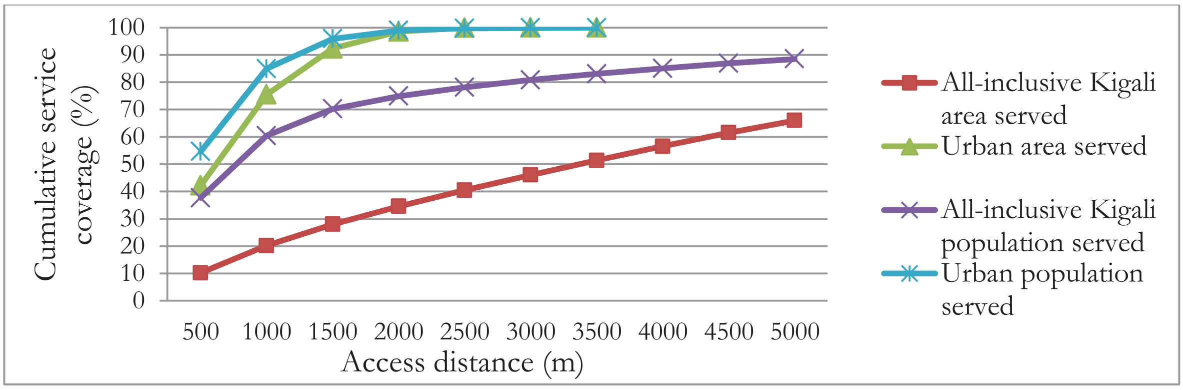


Figure 25: Access coverage curve to bus stops in Kigali

5.3. Route characteristics

5.3.1. Network density and Route overlapping

Network density represents the distribution of bus routes across zones passed by public transport route. It reveals the degree of consistency between residents and public bus routes. Contrary to network density, the route density takes into consideration the overlaps of routes.
The route overlapping describes repetition of bus routes at a particular road segment. At a particular location, a higher route overlap implies a greater opportunity for direct trips, and a great chance to travel to numerous destinations. However, the drawback is the fact that a high route overlap is probable to induce the traffic congestion.

The total length of Kigali bus route network is 127 km, and the total length of bus routes in Kigali is 266 km. Hence the corresponding route overlapping coefficient is equivalent to 2.1. This coefficient is somewhat low compared on a maximum threshold of 5. However, based on a disaggregated view as shown in Figure 26, the roads segments closer to the main city hubs (i.e. Kigali City Center, Nyabugogo & Remera) have a relatively higher routes overlap. This implies that in Kigali, except in main city hubs, there is a considerable less opportunity for direct trip to numerous destinations by public transport. According to(Guihaire & Hao, 2008), when direct trips are insufficient, the demand can be considered unsatisfied.

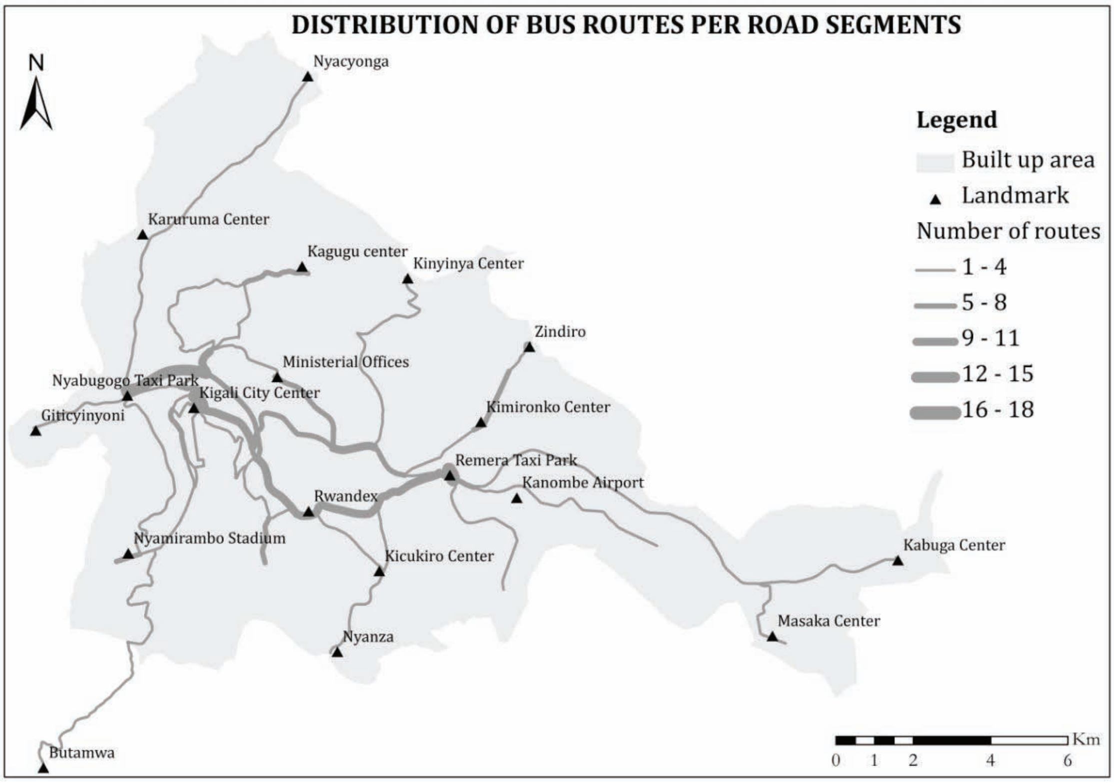


Figure 26: Distribution of bus routes per road segment

Figure 27 illustrates the public transport network density across the city of Kigali. The high network density is observed also nearby the main CBD (i.e. Kigali City Center) and within areas covering the main city hubs (i.e. Nyabugogo, Remera, Rwandex & Nyamirambo). A high network density reflects at large, a short walking distance to public transport service within a particular area.

Except in the areas covering the main hubs, the network density is somewhat low in general, based on a minimum threshold of 2 km/km^2. However, the network density depends on the area considered as well; in our computation we relied on administrative sector boundaries to perform network density analysis.
A greater ease of access to public transport service is nearby the main hubs, considering that the high network density and high route overlap was observed in these areas.

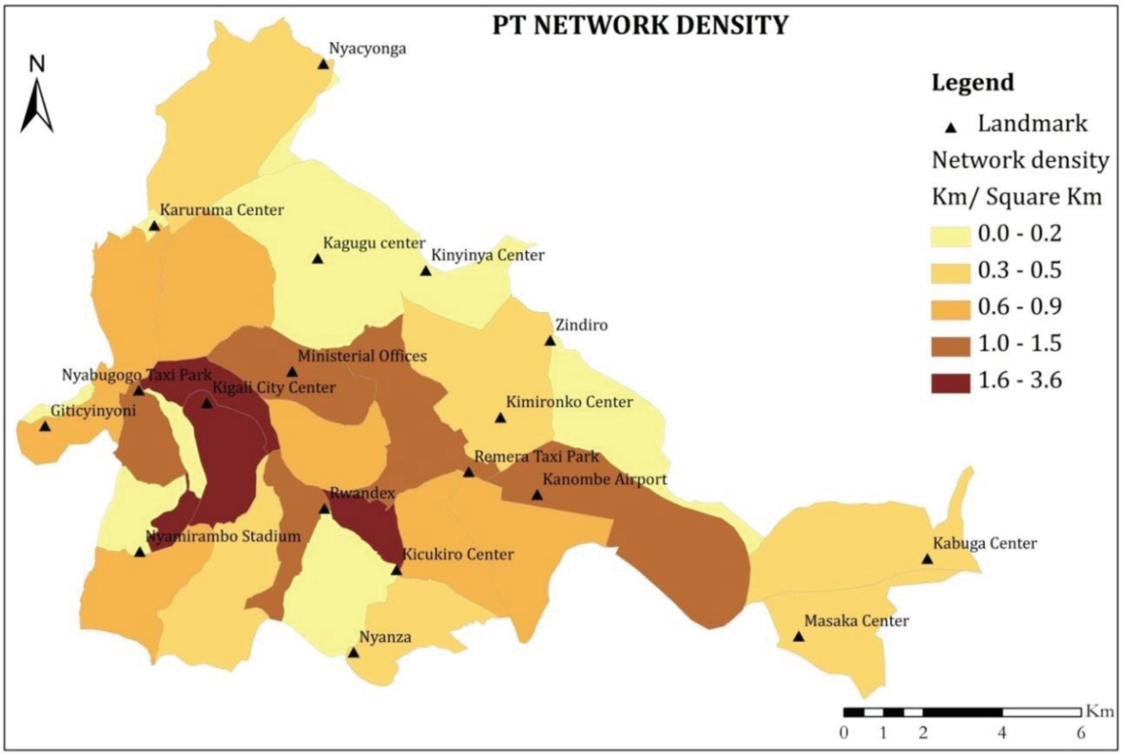


Figure 27: Public transport network density

5.3.2. Route length and bus stop spacing

The route length defines the travelled distance by bus service to link end-terminals. According to (Ceder, 2007), the route length should be kept within 40 to 100 minutes for one way travel, which is about 12 to 30 km, based on an average operating speed of 20km/h. Based on this standard, the bus routes in Kigali are even shorter, and they are supposed to be acceptable. In fact, the average bus route length in Kigali is 7.5 km.
In addition to bus routes, the location and spacing of bus stops are crucial elements of public transport, since these are points at which passengers access services. The average bus stop spacing along the route indirectly interprets whether the bus stops are redundant or insufficient. Redundant bus stops would increase the total travel time, especially in situation where buses have to stop at each bus stop, such as the case of bus service in Kigali. However, an insufficient bus stop would result in poor service coverage (Schöbel, 2006). Normally, a trade-off is determined by a specific public transport service standard, with a consideration of population density and land-use patterns of a particular location (Kimpel, Dueker, & El-Geneidy, 2006; White, 2002).

Figure 28 indicates the length and average bus stop spacing of each bus line in Kigali. Actually, the average bus stop spacing in Kigali is 697 m, which is slightly high compared to the identified threshold, based on which, the bus stop spacing should be in the range of 300 m to 600 m. To improve this, a more disaggregated analysis should identify an optimum spacing at each route, with a consideration of land-use patterns, type of service and population density within a particular location. Noteworthy to observed is the fact that, routes operating on unpaved roads (i.e. line 29 & 34), and those connecting city hubs and urban fringes (i.e. lines 9, 15, 16, 20 & 29), have higher bus route spacing.

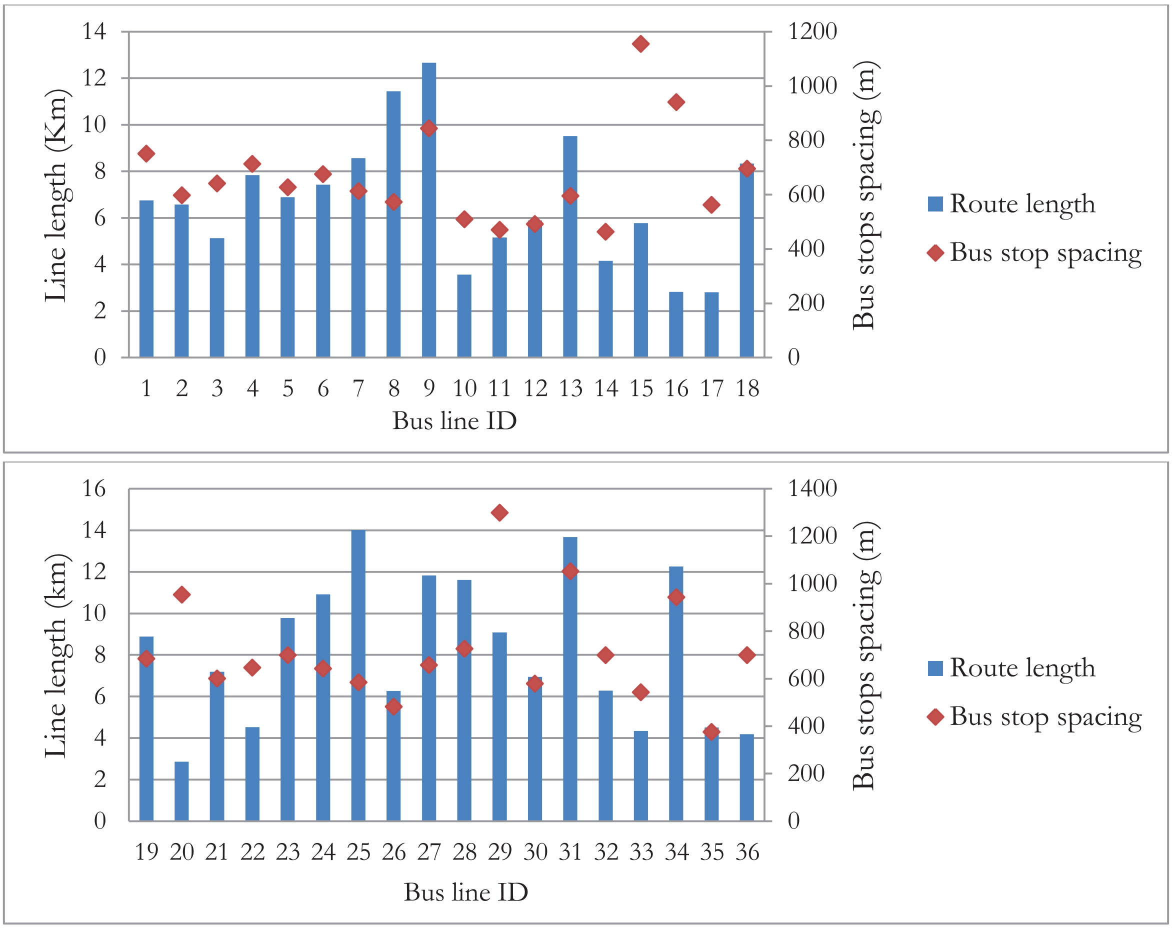


Figure 28: Route length vs bus stop spacing

5.4. Offered service capacity

Service capacity represents the capability of a public transport system to transport a given passenger volume on a bus line under prevailing conditions (Vuchic, 2005).

Service capacity can be expressed through offered capacity, this depend on the number of buses in service, their operating speeds and headways.

5.4.1. Observed frequency and operating speed

Figure 29 shows the number of trips of buses passed on a particular road segment per day. The greater concentration of number of trips of buses is stretched between the main CBD (i.e. Kigali City center) and the main city hubs (i.e. Nyabugogo, Remera, Rwandex, Nyamirambo). However, a high frequency of small buses may not cope with the demand on a particular line; rather it contributes to the traffic congestion where buses operate in mixed traffic, which is the case of bus services in Kigali. According to (Ceder, 2007), the minimum headway should be at most between 2 and 3 minutes.

Figure 30 indicates the proportion of buses operating on a particular bus line according to their size, and the average headway per day.

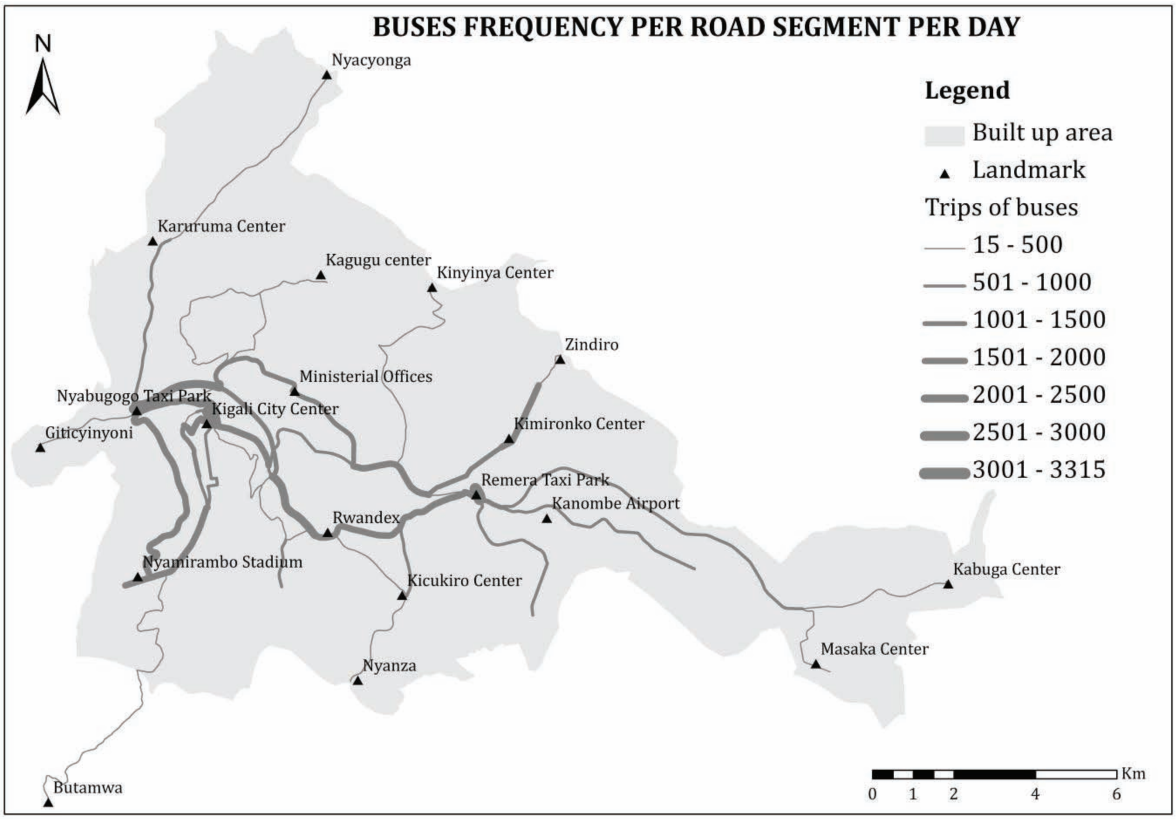
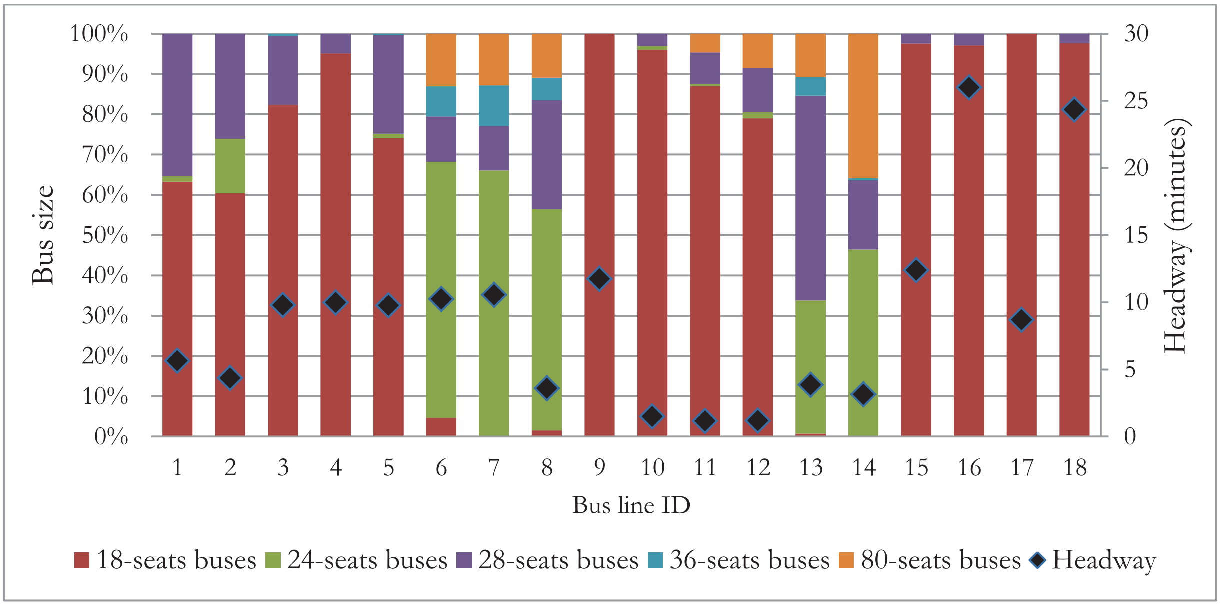


Figure 29: Buses frequency per road segment

From Figure 30, it is shown that 9 bus lines (i.e. bus lines 10, 11, 12, 14, 22, 25, 26, 32 and 35) out of 36 bus lines have headways below 3 minutes. Consequently, these lines are likely to be the most congested in the city considering that bus services operate in mixed traffic.



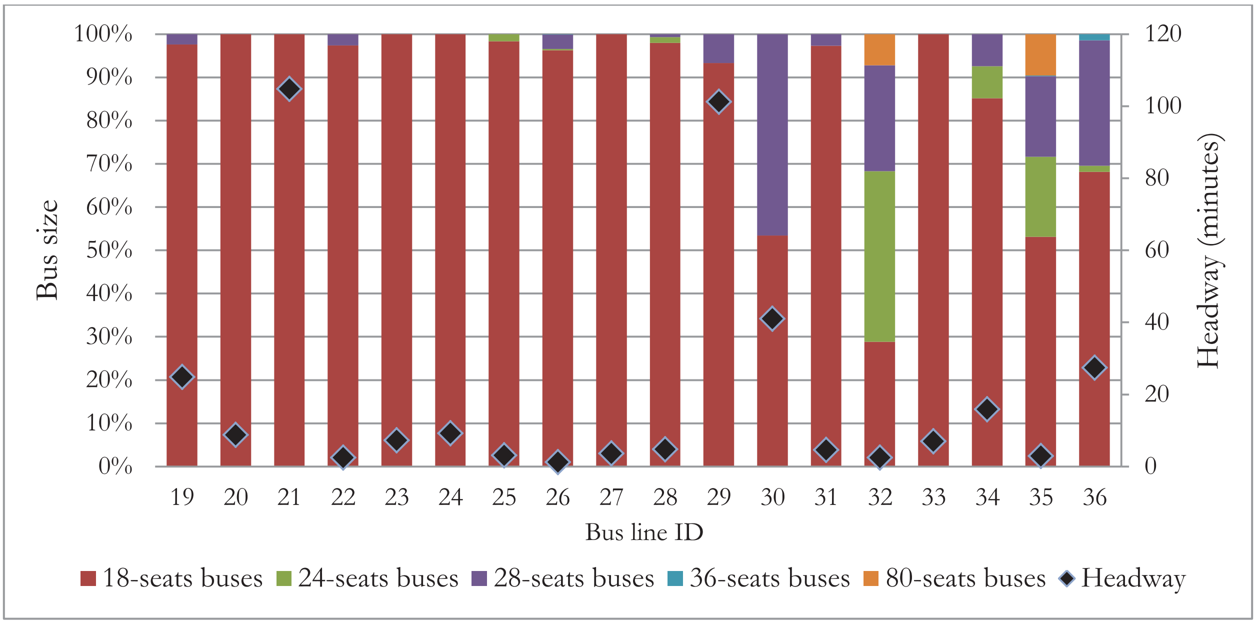
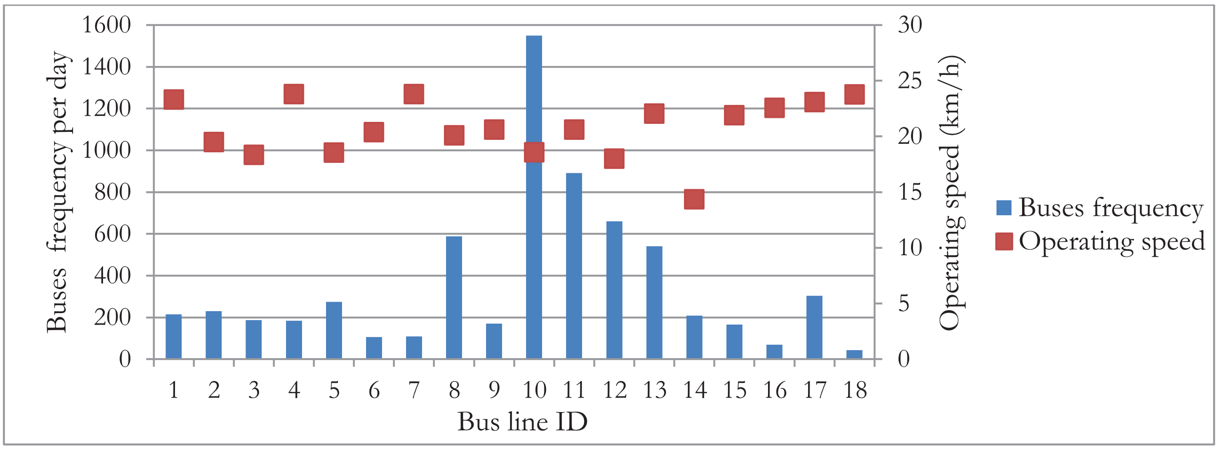


Figure 30: Headway vs proportion of bus size type per bus line

Bus frequency may affect the operating speed as well. Figure 31 indicates the buses frequency on a particular line, and the average operating speed taking into account running speeds, delays in traffic, and stopping on route to enable passengers to board or alight.

Normally, a high bus frequency induces low operating speed. However, it was found that there is no significant relationship between the buses frequency and the average operating speed of buses in Kigali. Apart of buses frequency, the average operating speed of buses in Kigali clearly depends on the prevailing road and traffic conditions, since the buses operate in a mixed traffic.

The average operating speed of buses in Kigali is 21 km/h. According to (Armstrong-Wright & Thiriez, 1987; White, 2002), this speed is relatively acceptable. Based on figures 28, 30 and 31, it was found that the high frequency is observed in relatively short bus lines operated by high proportion of small buses.



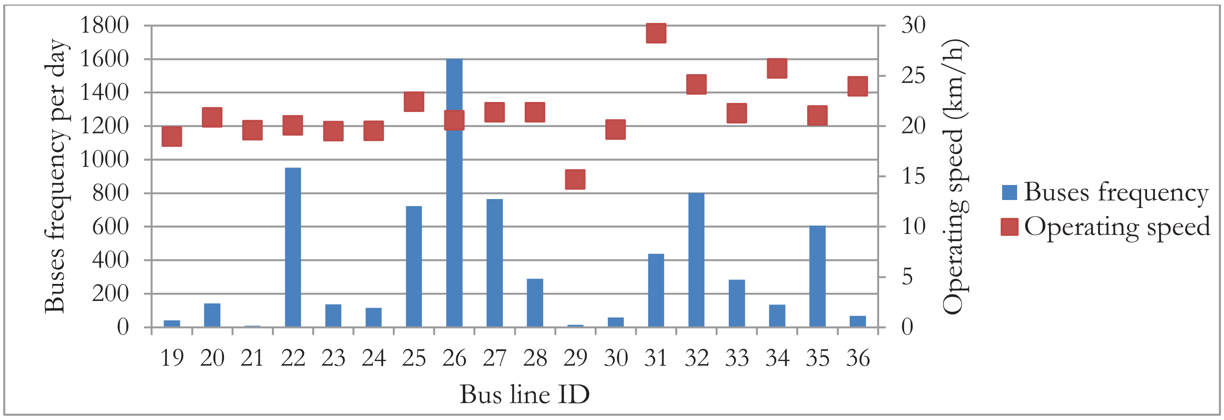


Figure 31: Bus frequency vs operating speed

5.4.2. Seating capacity and service span

A relatively high frequency of bus services may induce the availability of service. However, the bus frequency itself does not clearly give a picture of offered service capacity in case the operating buses vary considerably in size, which is the case in Kigali. Yet, the seating capacity of operating bus plays a big role. Figure 32 elucidates the offered seats per road segment passed by a bus.

It is illustrated that much seating capacity is allocated in routes connecting the main hubs of the city such as Kigali City Centre, Nyamirambo, Nyabugogo, Remera and Kimironko. This indicates where many interactions occur within the city. The greater number of buses generally connects the main city hubs (see Figure 29). Less interaction is observed in the fringes of the city.

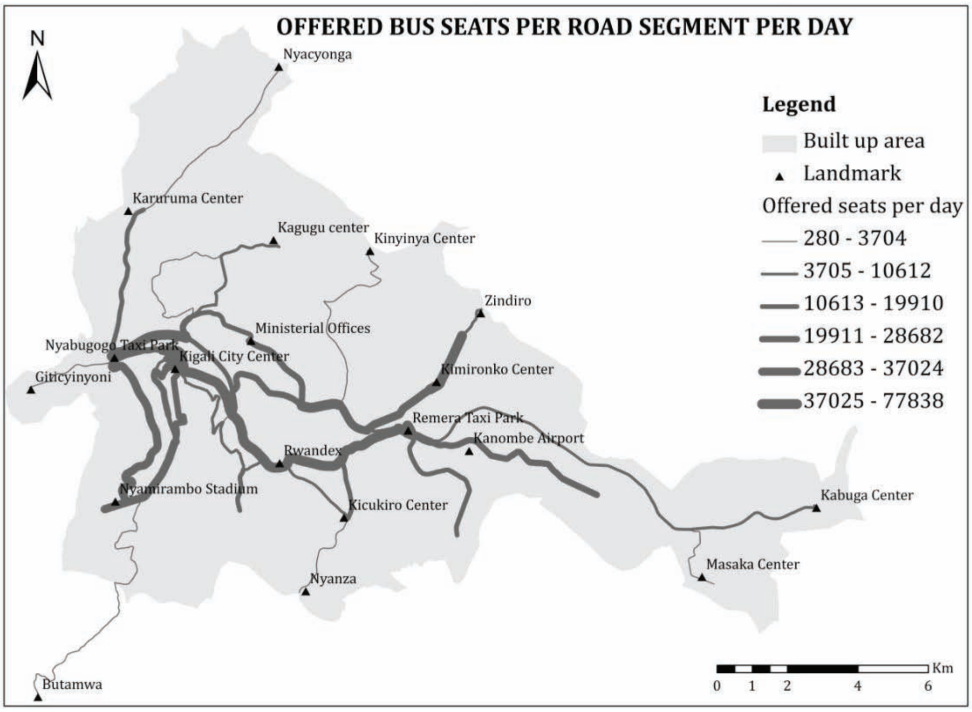


Figure 32: Offered bus seating capacity per road segment

The service capacity depends on service span as well. It reveals in which period of the day, bus service is available in different parts of the city. This is based on operating hours of a particular bus line. Figure 33 indicates the total offered seats and operating hours per day. The observed average service span is 15 hours, which is slightly lower than 18 hours, the acceptable service span (Vuchic, 2005). This has an effect on the convenience of public transport for passengers, and can constrain the types and number of trips that can be made by public transport.

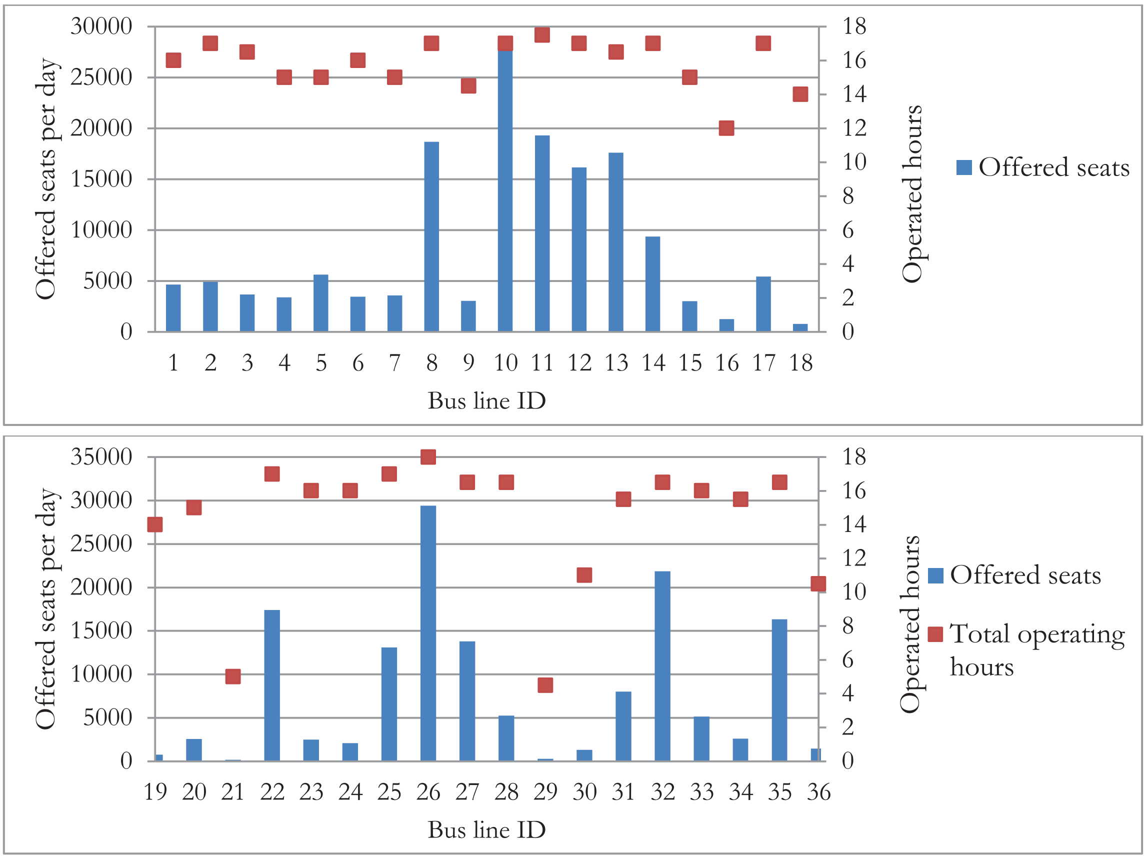


Figure 33: Offered seats vs operated hours per bus line

5.5. Concluding remarks

In this chapter, we presented the score of adopted performance indicators. Almost all identified performance indicators, except the operating speed, have a relatively low performance compared to the set thresholds. In fact, the existing public transport network covers only 42% of the urban area 54% of Kigali urban population, based on a buffer of 500 metres from a particular bus stop. The network density is considerably low in most locations, except nearby CBDs. The average bus stop spacing in Kigali is 697 metres, which is slightly high compared to the identified threshold, based on which, the bus stop spacing should be in the range of 300 metres to 600 metres. The route overlapping coefficient is equivalent to 2.1, which is somewhat low compared on a maximum threshold of 5. A better access to public transport service is only observed nearby the main city hubs, considering that the high network density and high route overlap are observed in these areas. This implies that in Kigali, except in main city hubs, there is less opportunity for direct trip to numerous destinations by public transport.

The average service span is 15 hours, which is slightly low, and is likely to constrain the number of trips that can be made by public transport. The headway is less than 10 minutes in most bus lines, and even less than 3 minutes in a number of bus lines. On other hand, the high frequency (i.e. low headway) of small buses does not cope with the demand; rather it contributes to the traffic congestion considering that buses operate in mixed traffic.

In the next chapter, individual indicators will be aggregated in order to ascertain the overall performance of public transport service. On basis of the results, improvements will be identified

6. OVERALL PERFORMANCE ASSESSMENT

6.1. Introduction

Performance measurement is fundamental for assessing public transport service, and a most useful tool for monitoring improving service (Eboli & Mazzulla, 2011). A review of performance measures was presented in chapter 2. The important notice is the fact that performance measures should be tied to their goals and objectives; considering that performance is a broad term, and depends significantly upon perspective (George M, 1989; Kittelson et al., 2003). This chapter presents the overall performance of public transport system in Kigali, viewed from the passenger perspective. Particular attention is given to the spatial and temporal aspects jointly combined with seating capacity of service supply, in order to evaluate public transport service availability.

6.2. Distribution of potential transit demand

In the preceding chapter (i.e. chapter 4, section 4), we explained the estimation process of potential demand for public transport in Kigali using four-stage transport model. We estimated the trips generated at each hexagon. The cost between each pair of hexagons is based on the network travel time between them. The off road speed, pedestrian speed, is considered as 4.8 km per hour (Vuchic, 2002). The distribution of the trips was done through a doubly constrained gravity model, and the calibration of the model is based on the mean trip length (MTL). This task was performed using Flowmap software, and the estimated value for MTL was found equivalent to 1100 seconds.

Figure 34 illustrates the distribution of potential transit demand over the public transport network. The major flow is remarked in the city centre along the routes connecting the main city hubs.

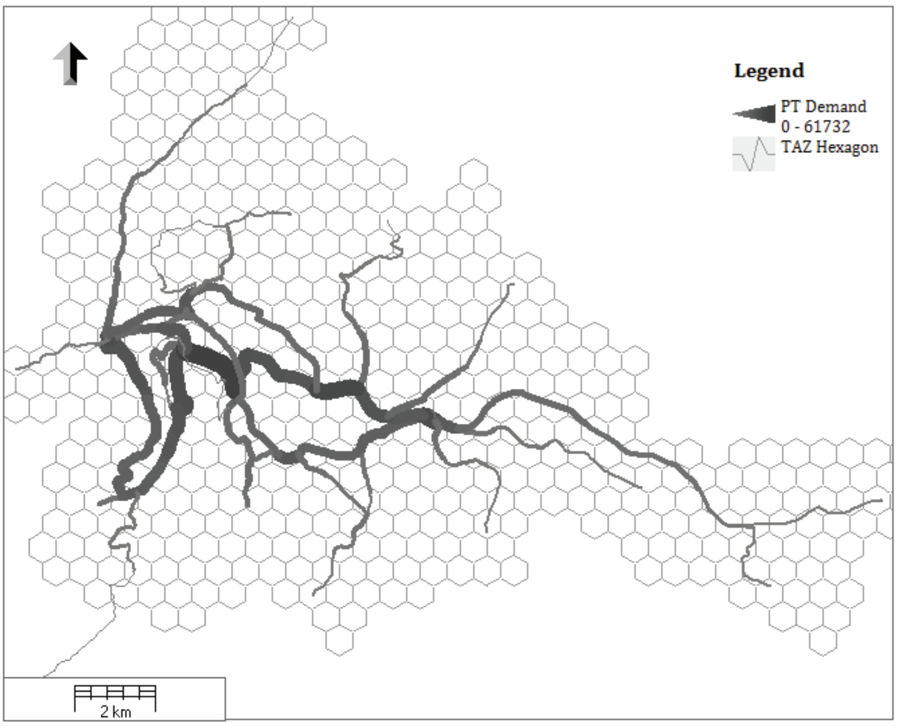


Figure 34: Distribution of trips to bus route network

6.3. Performance assessment

In this section, we will compare the potential transit demand with the offered service, in order to determine the performance of public transport supply. The overall assessment concept and the mathematical formulation of performance measurement are presented in chapter 4, section 5.

6.3.1. Assessment of public transport service capacity

Two steps were involved in the assessment of public transport service capacity. Firstly, we assigned the potential transit demand to bus route network, and later we computed the service capacity of road segments.

The modelling of potential transit demand was performed using 228 road splits made during trip assignment stage (see chapter 4, section 4). In order to ease the dynamic segmentation, the flow over these 228 road splits was aggregated to 78[3] bus route segments, based on the segment load-profile density.

The load-profile density ρ is the observed measure of the flow over the route (i.e. passenger-km) divided by the product of the length of the route and its maximum load. It is used to examine profile characteristics. High values of ρ indicate a relatively flat profile, whereas low values of ρ indicate load variability among the route stops (Ceder, 2007).
If ρ is higher than 0.5, the highest loaded split can represent the flow over the entire segment (Ceder, 2007). The average ρ in Kigali was found equivalent to 0.87 (see appendix 3); hence the highest loaded split represented the load over the entire road segment.
The load-profile density ρ for the segment *i* is determined by the following formula:

$$\rho_i = \frac{\sum_{j=1}^{J} P_{ij} L_{ij}}{P_{mi} L_i}$$

Where:
P_{ij} = the passenger flow at the split j of the segment i
L_{ij} = the length of the split j belonging to the segment j
P_{mi} = the passenger flow at the highest loaded split of the segment i
L_i = the length of the segment j

The public transport service capacity is based on the ratio of the potential transit demand on a road segment and the offered seating capacity on that segment weighted by the waiting times and service span. The acceptable waiting time considered is 20 minutes, whereas 18 hours are considered as the acceptable service span (Armstrong-Wright & Thiriez, 1987; Ceder, 2007; Vuchic, 2005). The theoretical background, the weighting and the aggregation are explicitly explained in chapter 4, section 5.

Figure 35 illustrates the public transport service capacity of road segment operated by buses. The index value lower than 1 indicates where potential demand is higher than the offered service, whereas the index value higher than 1 indicates where the offered service is higher than the demand. For example, on a road

[3] These 78 road segments were made while constructing the bus route network as shown in Figure 13

segment with an index equal to 1.5, it implies that the offered capacity is 1.5 times more the potential demand. Whereas, an index equal to 0.4, it implies that the offered capacity is 40% of the potential demand. Despite the variability between road segments, the findings show that there is a considerable shortfall of service in most road segments (67% of road segments). In fact, the results show that there is insufficient of service in 52 road segments out of 78 road segments, and the shortfall is more observed in fringes areas compared to the central areas.

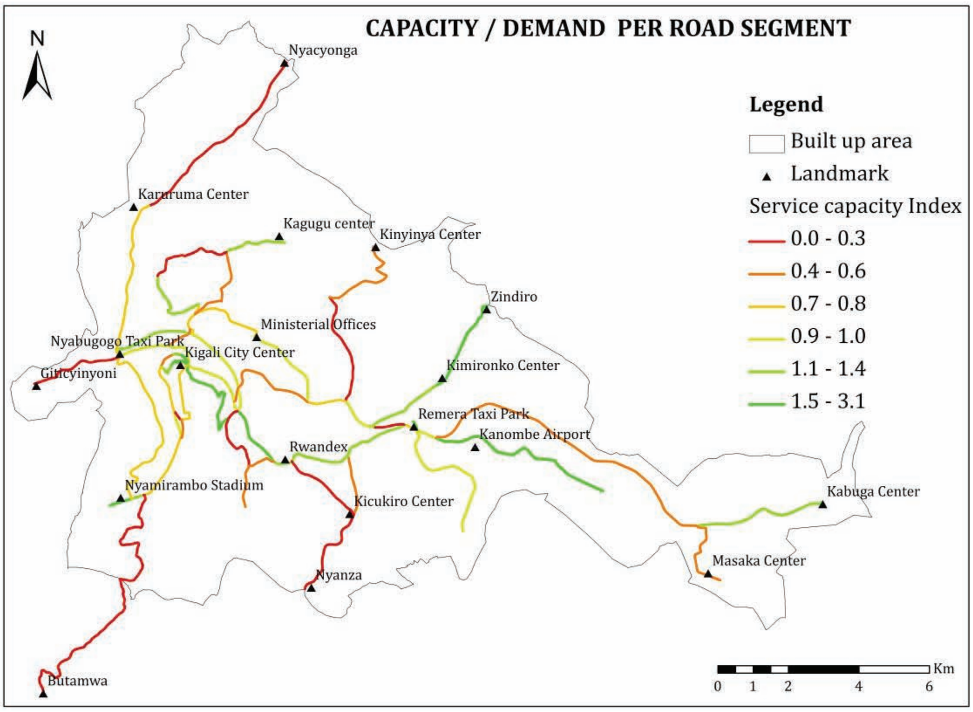


Figure 35: Public transport service capacity of road segment

6.3.2. Temporal availability of public transport service

The level of temporal availability of public transport service is based on the capacity of public transport supply to cope with the potential demand, regardless the access distance required to reach the service.

The measure of temporal availability reveals the ability of the system to cope with the subjected demand. The assessment firstly identified the catchment area of each bus stop, and the service capacity of each bus stop. The service capacity of a bus stop is defined by the service capacity of the road segment on which it belongs.

The amount of trips served based on the service capacity of public transport is determined by multiplying the generated trips within a bus stop catchment area with its service capacity index. Note that in this regard, the service capacity index value cannot be more than 1, considering that offering much capacity doesn't increase the generated trips in a particular area.

Figure 36 illustrates the catchment area of each bus stop and its service capacity index. We assume that passengers get public transport service through the nearest bus stop, with regards that trips are uniformly distributed within the area considered.

Figure 37 demonstrates accordingly the level of temporal availability of public transport service in different zones of the city. This level is the proportion of the trips served within a hexagon based on service capacity of public transport and the total trips generated in a hexagon. The results show that the current public transport supply can serve up to 65% of potential transit demand.

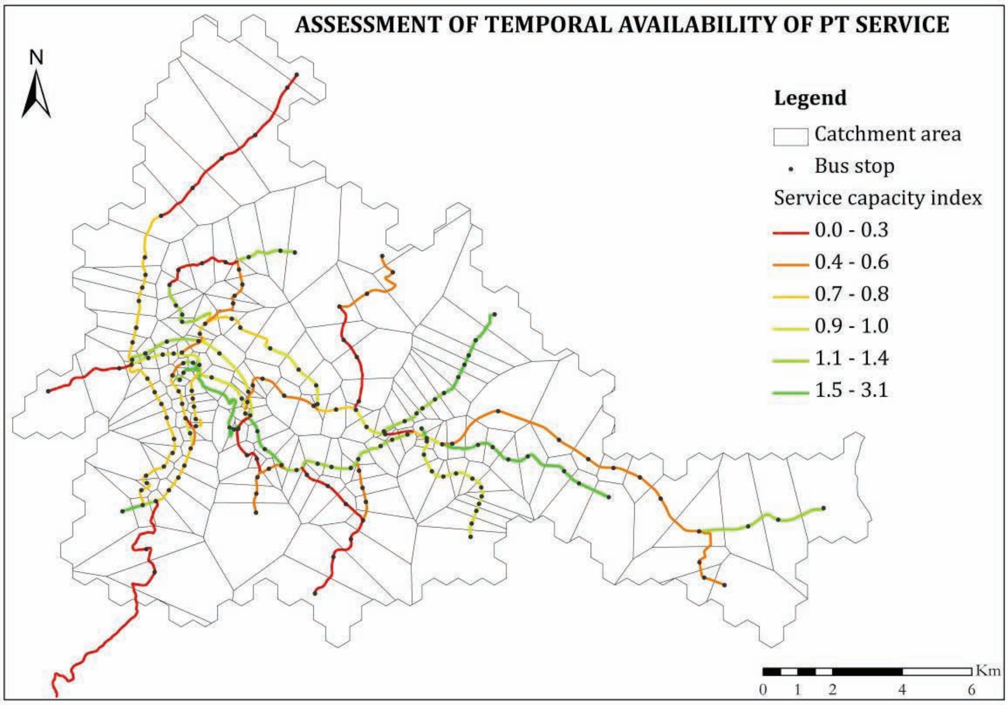


Figure 36: Catchment areas of bus stops and their service capacity

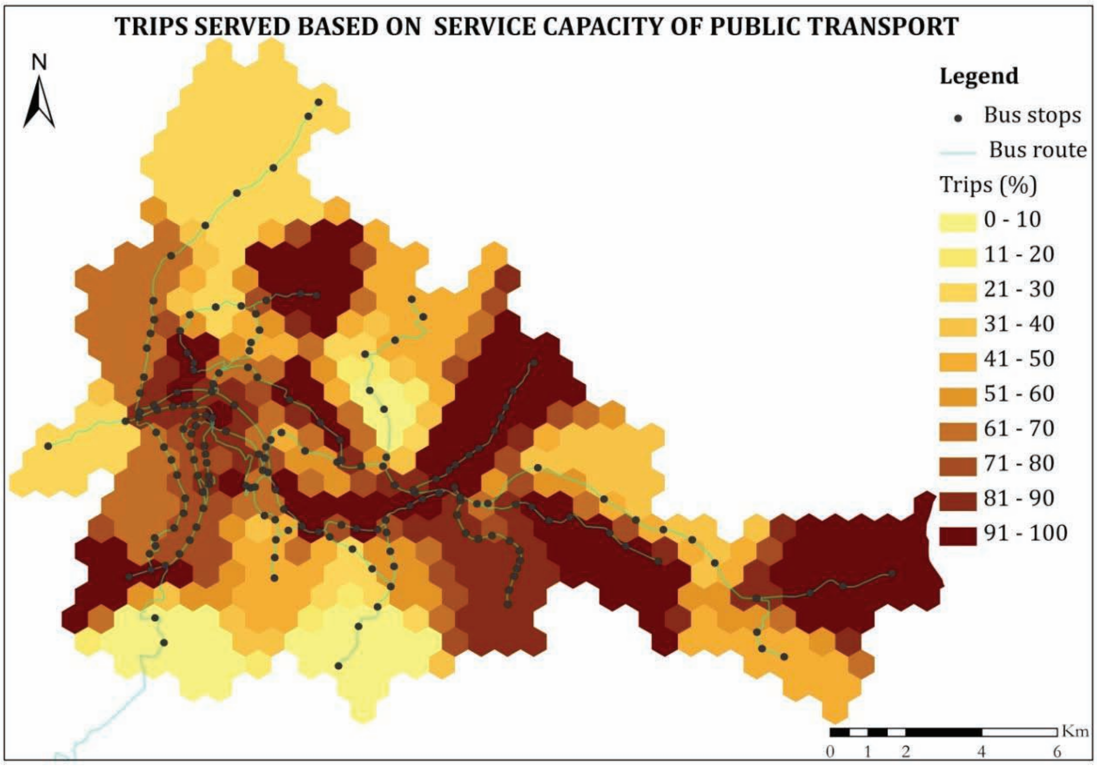


Figure 37: Trips served based on service capacity of public transport

In areas where there is a high level of temporal availability of public transport service, it means that the demand of public transport service in those areas can be served, since the service capacity of their nearest bus stop is enough to cope with the subjected demand. In other words, passengers in these areas can get the public transport service in case they reach to their nearest bus stop. The level of temporal availability in a specific area indicates how much demand can be served by public transport in that area.

6.3.3. Spatial availability of public transport service

The level of spatial availability of public transport service is based on the ease at which public transport service can be reached, without considering the service capacity available to cope with the demand.
Figure 38 illustrates the acceptable buffer coverage of each bus stop, which is 500 metres from a bus stop.

The assessment consists of computing the amount of trips generated from each hexagon which falls in the defined bus stop coverage. Accordingly, the level of spatial availability (i.e. percentage of trips served) is the proportion of trips of an hexagon which falls in the defined bus stop coverage and total trips generated in that hexagon, with a regard that trips are uniformly distributed within the hexagon considered. We assume also that passengers get public transport service through the nearest bus stop.

Figure 39 illustrates the level of spatial availability of public transport service in different zones of the city. The results show that only 53% of potential transit demand is served by the current public transport.

In areas where there is a high level of spatial availability, it means that the demand of public transport in those areas have a good access to public transport service, since they are located nearby bus stop. In other words, passengers in these areas have a better access to public transport service. The level of spatial availability indicates how much demand has a good access to public transport service in that area.

On the other hand, it is important to note that the level of spatial availability depends on the adopted threshold (i.e. acceptable access distance). Figure 40 shows the level of spatial availability in case 1000 metres is considered as the acceptable distance to reach a bus stop. The result shows that 82% of potential transit demand is met, in case this threshold is adopted.

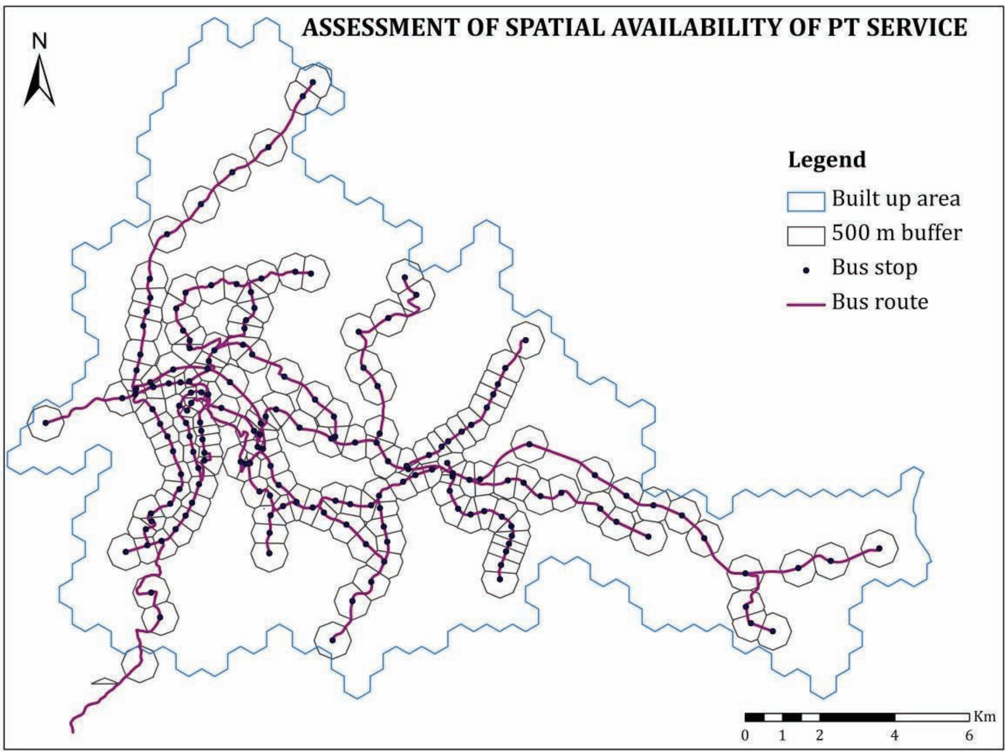


Figure 38: Bus stop coverage (500 metres)

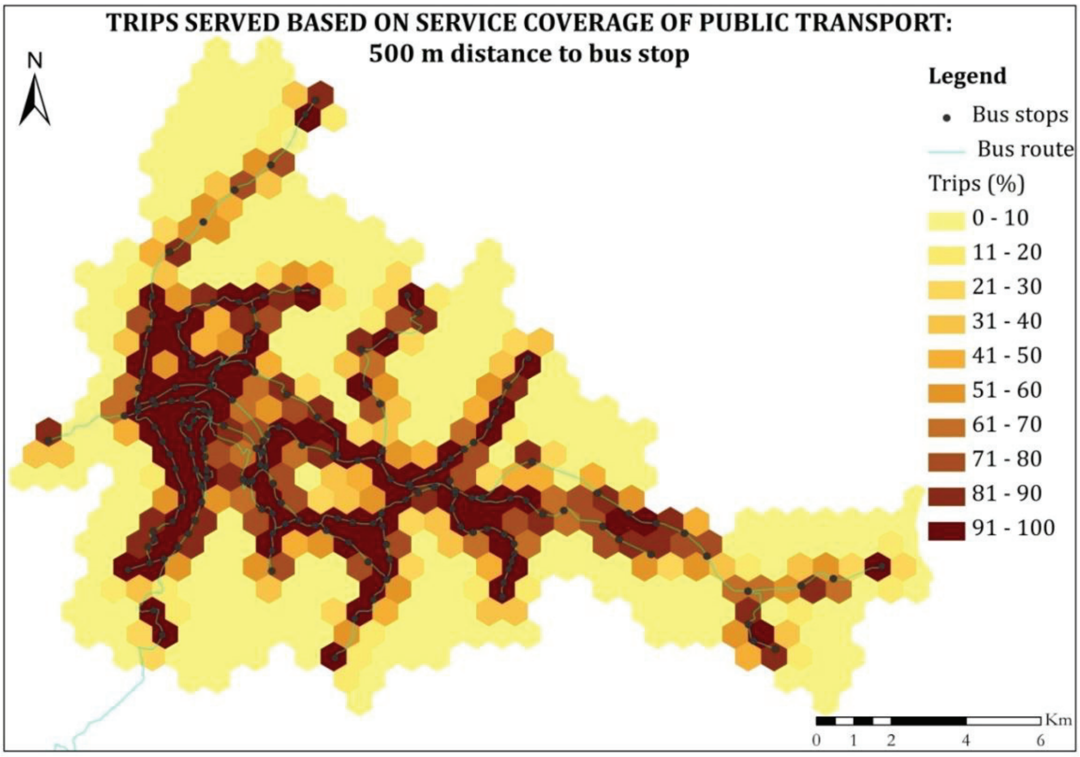


Figure 39: Trips served based on 500 metres access coverage of public transport

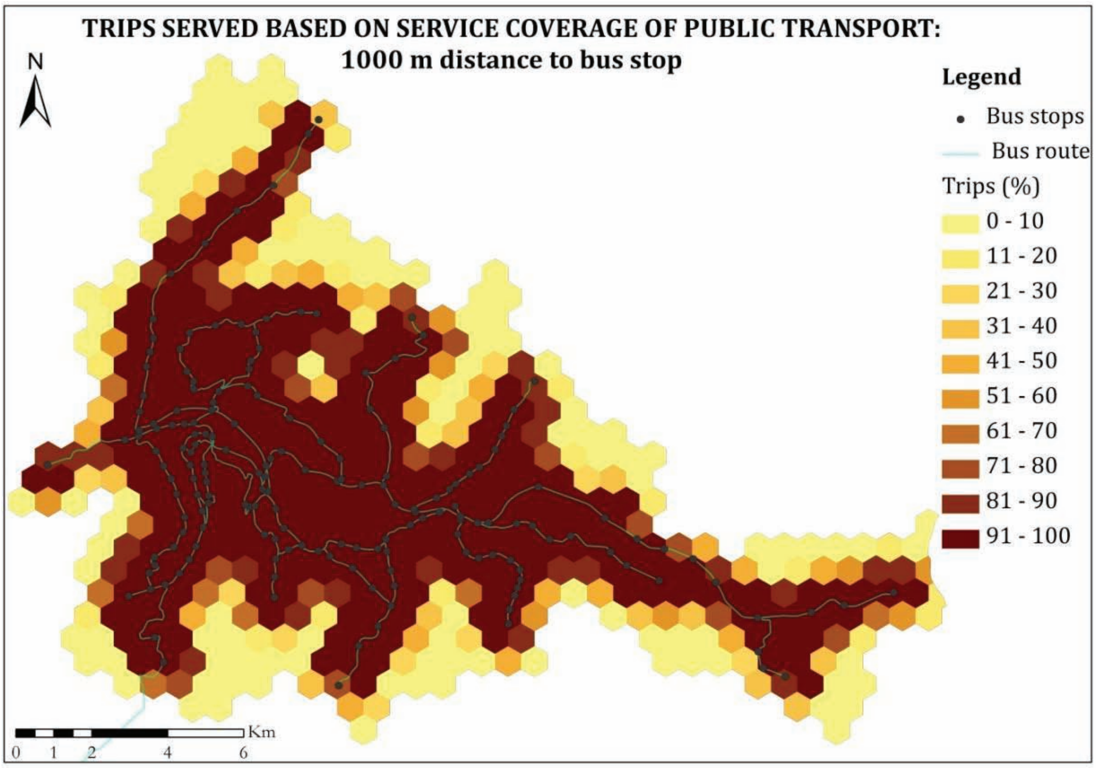


Figure 40: Trips served based on 1000 metres access coverage of public transport

6.3.4. Public transport service availability

Public transport service availability is determined by the spatial and temporal aspects jointly combined with seating capacity of service supply. The assessment of public transport service availability identifies the number of trips in a given hexagon which are adequately served. In a particular hexagon, the trips which are adequately served are the number of trips served based on the service capacity of public transport supply, which falls in the defined bus stop coverage.

In other words, public transport service availability in a particular zone is defined by two conditions; bus stops being nearby 500 meters, and the available service capacity being enough to cope with the potential demand. The first component defines the spatial availability of the service, whereas the second component defines the temporal availability of the service. The combination of these two components of service provides a reliable measurement for public transport service performance assessment.

Figure 41 describes the operationalization of service performance assessment in ArcGIS, whereas the overall performance framework and the analysis structure are respectively presented in Figure 20 and Figure 21.
Figure 42 illustrates the assessment of public transport service performance which includes spatial and temporal aspects jointly combined with seating capacity of service supply.

The results show that only 37% of the trips are adequately served in case, both spatial and temporal aspects of service supply are considered.

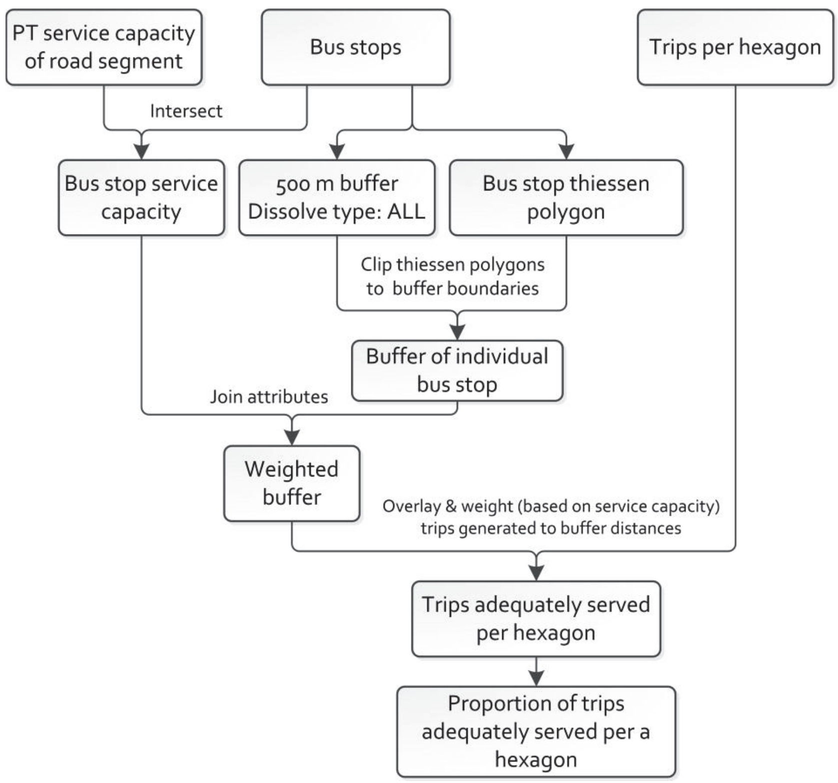


Figure 41: Operationalization of the overall service performance assessment

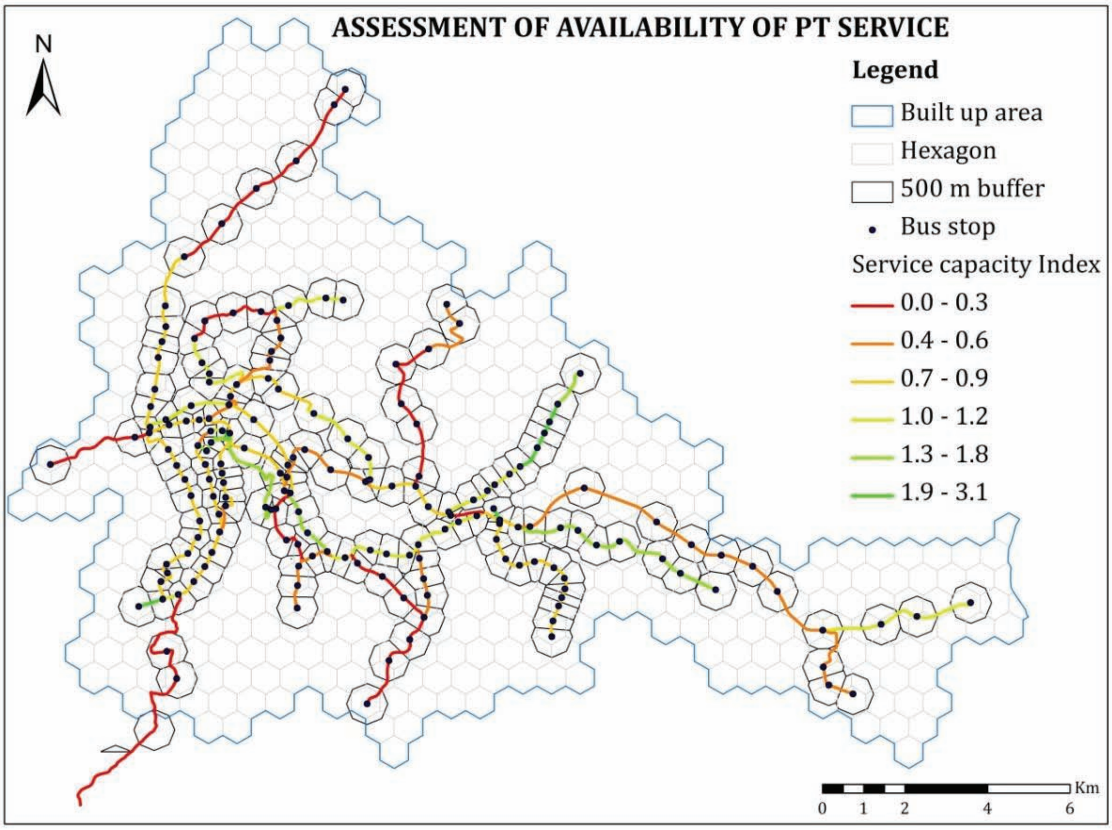


Figure 42: Assessment of public transport service performance

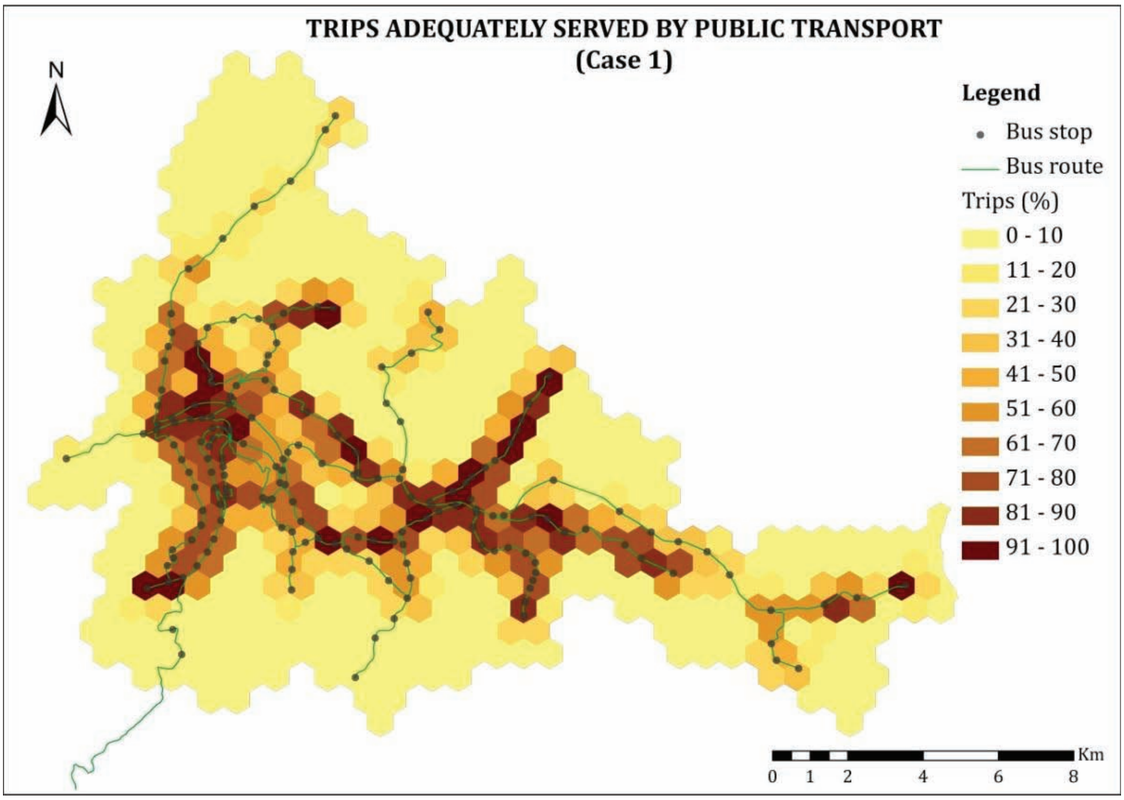


Figure 43: Level of public transport service availability in Kigali City (Case 1)

In areas where there is a high level of service availability, it means that the demand of public transport in those areas have a good access to public transport service and they can get public transport service in case they reach to their nearest bus stop, since they are located nearby bus stops and the service capacity of their nearest bus stop is enough to cope with the subjected demand. In other words, passengers in these areas have a better access to public transport service and they are provided enough service. The level of service availability indicates how much demand is adequately served by public transport service in that area.

Noteworthy to mention is the fact that thresholds considered play a big role. For example, in case 1000 metres is considered as the acceptable distance to reach a bus stop, the level of spatial availability increase from 53% to 82% as shown in Figure 39 and Figure 40. Accordingly, the level of service availability increase also from 37% to 55%. Figure 45 illustrates the service performance in this alternative, which is the number of trips adequately served by public transport in this second case.

However, the results show that in both cases the level of service availability in Kigali is low. It is observed that there is a considerable scarcity of public transport service in different locations of the city. This makes public transport unreliable and it ceases to be useful to the people who want to use it, especially in the areas with lower level of service availability.

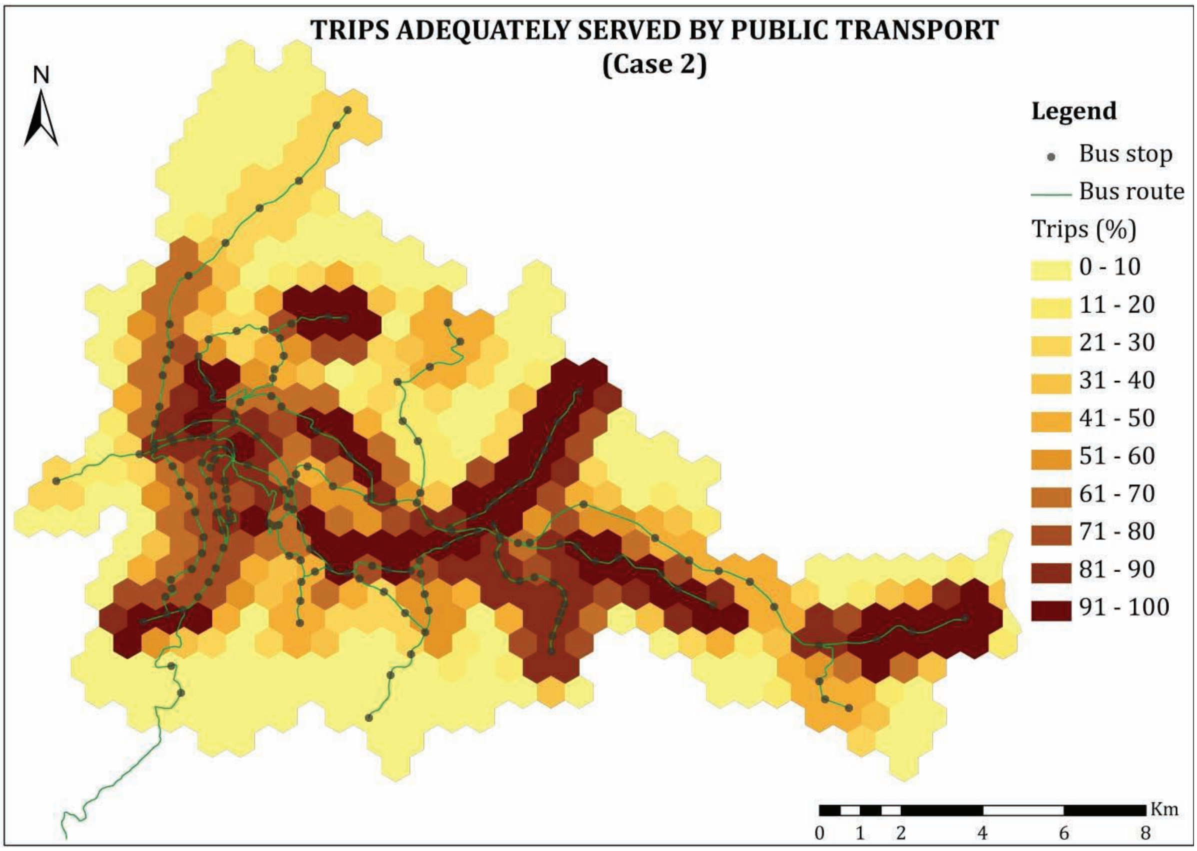


Figure 44: Level of public transport service availability in Kigali City (Case 2)

6.4. Identification of improvements

This assessment study of service performance of public transport in Kigali, addressed two critical issues; accessibility to bus stops which defines the level of spatial availability of service, and the capacity of service available to cope with the demand, which describes the temporal availability aspect. The results proved that there is an insufficient of public transport service in Kigali city. To respond on this regard, many interventions can be generated to enhance the public transport service performance in Kigali. Among them, this study suggested two interventions. One is to extend the service coverage, considering that only 54% of the total population is provided acceptable access distance to public transport based on the 500 metre standard. The second would be to enhance the service capacity of existing buses, considering that the current public transport cannot serve more than 65% of the demand.

6.4.1. Extending service coverage

Due to limited extent of public transport route network, some locations of the city are deprived of public transport service, and people have to walk considerable distances to access bus stops. The proximity analysis (see Figure 23), reveals that the largest distance travelled to reach the service was 3 km.
This could be supported by the fact that the level of infrastructure in Kigali was intended to accommodate about 450,000 people (The World Bank, 2011a), whereas the number of inhabitants of Kigali currently is approximately 1,000,000. These highlight the point that the improvement of bus route network would be one of the potential solutions to expand the service within the city.

From the existing road network, we identified suitable roads for public transport network extension. This was adopted as the more viable option economically than constructing new roads. The operation consists of three main procedures; defining relevant factors for suitability assessment, weighting factors based on targeted vision, and identification of necessary layers for suitability analysis (Keshkamat, Looijen, & Zuidgeest, 2009; Orton Family Foundation & Placeways LLC, 2010).

The Scenario 360 suitability decision tool has been used to ascertain the suitable roads for future extension of public transport service. The tool is an extension of ArcGIS which helps to set up an analysis that scores spatial features based on their suitability or desirability for a particular application (Orton Family Foundation & Placeways LLC, 2010).

Table 20 explains the relevance of each factor and its weight. In the set of identified factors, the relative weight of each suitability factor determines its relevance vis-à-vis to other factors, and the sum of the weights must be equal to 10.

Figure 48 illustrates suitability roads for public transport extension. The suitability score varies from 0 to 100, where a high score value describes the more suitable is the road for bus route expansion. From the figure 48, the roads with green colour are the most suitable for bus route expansion.

The suitability analysis indicates where route expansion is needed mainly based on where there is a shortage of public transport service and high population density, considering that high density areas are the most potential generators of transit demand.

Table 20: List of factors and the explanation for bus route expansion

Factor	Layer	Weight	Explanation
Better in no served area	Service availability (Case1)	4	Much preference was given to the locations with insufficient bus service as identified in Figure 43
Better in dense area	Population density	3	The high density areas are the most potential generators of transit demand. Providing bus routes in these areas would spread the demand, and ease the traffic considering that buses in Kigali operate in mixed traffic.
Better in no narrowed road	Roads classification	2	Some roads in Kigali are not suitable for adequate car traffic. Economical and feasible option would be to allocate buses along the existing adequate roads. A preference was given to road with a higher classification. The given layer has 5 types of roads, ranging from 1 to 5 based on their adequacy for car traffic
Better closer to current bus route network	Bus route network	1	A preference was given to proximity to the existing bus route network. This would ease the trip interaction, and avoid a collection of routes rather than an interconnected network.

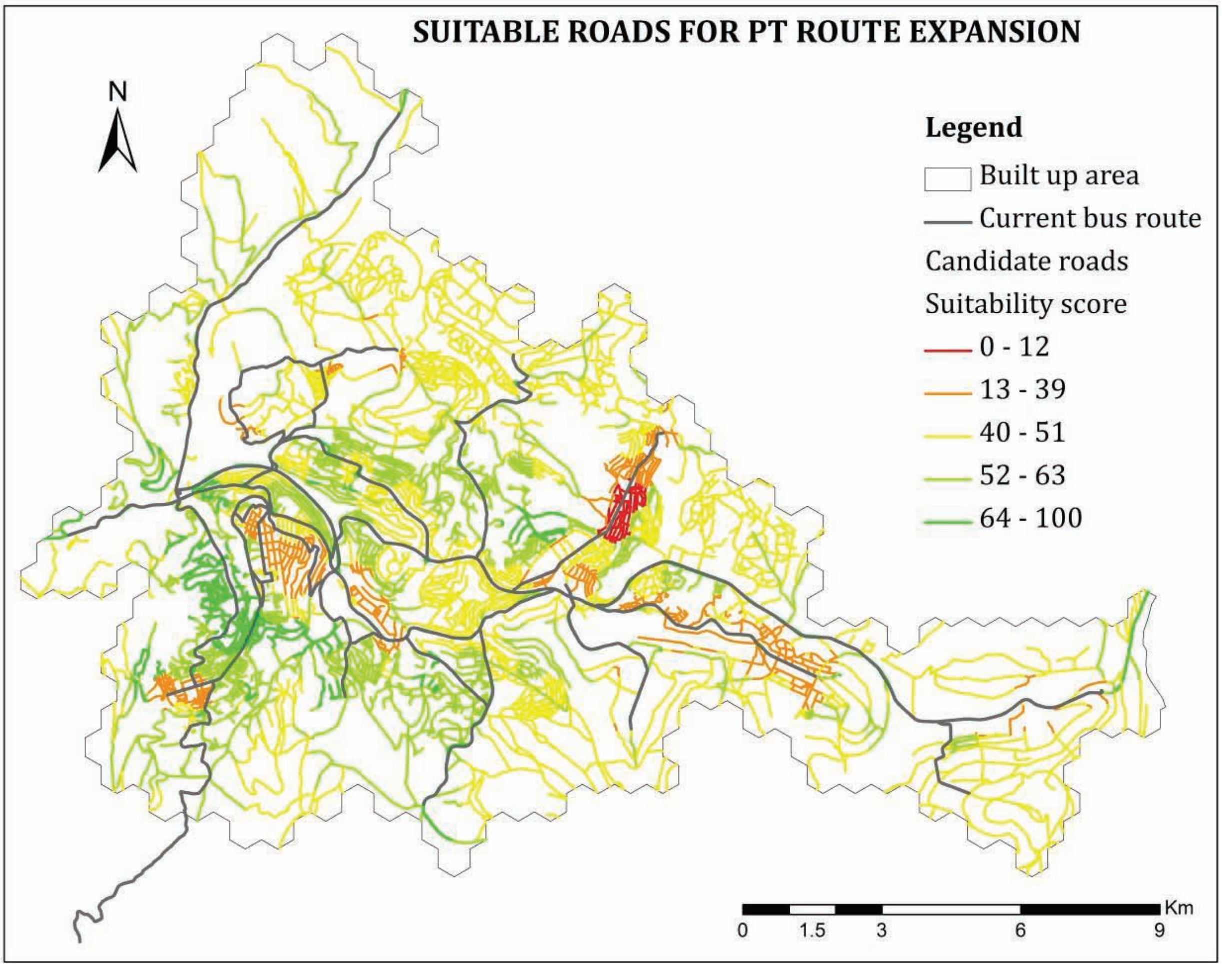


Figure 45: Suitable roads for bus route network expansion

6.4.2. Service capacity enhancement

Based on the temporal availability analysis (see Figure 37), the current public transport system cannot serve more than 65% of the demand. This defines the necessity of more buses to address the insufficiency of transport service.

Figure 30 showed that in some bus lines, the headway is lower than 3 minutes, the minimum acceptable. Larger buses (i.e. higher seating capacity) are suggested in such lines, considering that most of these lines are operated by a relatively high proportion of 18-seats buses. Yet, a more specific study would be needed to determine the optimum size and mix of the required buses for a particular line. Currently, 77 % of bus trips are made by small buses as shown in Figure 47.

Therefore, based on Figure 30 large buses are needed at bus lines with headway below than 3 minutes and high proportion of small buses. In this respect, Bus lines 25, 22, 26, 10, 11, & 12 are respectively priorities candidates for large buses allocation. For bus lines with headway greater than 20 minutes, the maximum acceptable waiting time, the increase of dispatched buses would be a favourable solution to cope with demand in case there is a shortage of bus service. the service in bus lines 21 & 29 would be improved by just increasing the frequency of buses.

These improvements are advocated with a regard that the current public transport route network is maintained. However, in case the current network is expanded, considering that it just covers 42% of the urban area based upon the 500 m buffer coverage, a rationalization study would be required to identify the frequency and the size of the buses for the prospective bus lines. This is based on the fact that new routes are likely to induce the spread of demand.

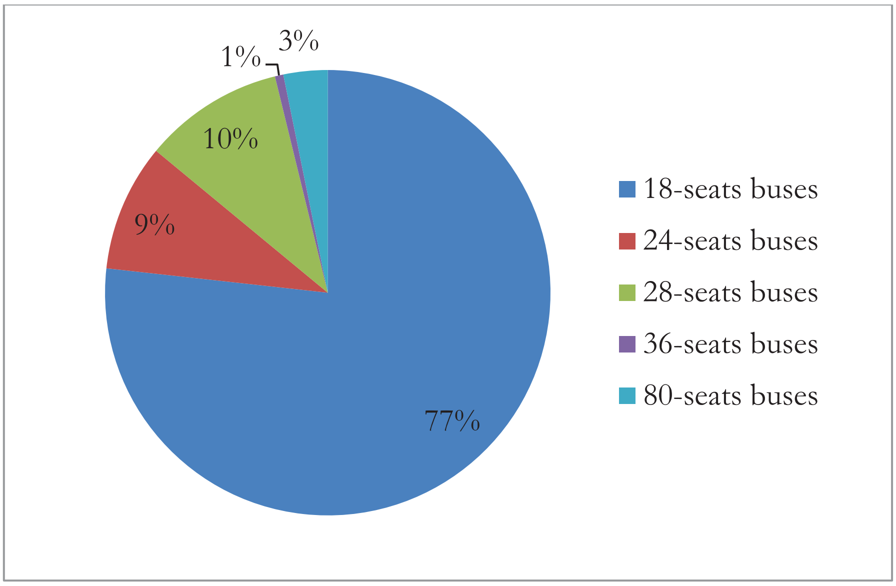


Figure 46: Proportion of bus trips per day according to bus size

7. CONCLUSION AND RECOMMENDATIONS

7.1. Conclusion

Public transport in Kigali faces multiple challenges stemming from a mismatch between the supply of public transport services and transit demand. An assessment of available public transport service was carried out to determine the level of service availability across different locations of the city. To assess the discrepancy between supply and demand, a number of route performance indicators, and service capacity performance indicators were developed to ascertain the service performance, as well as suggest interventions leading to service improvement.

Performance measurements were developed to identify the level of public transport service availability in different locations in Kigali at spatially disaggregated level. Overall, current public transport can serve up to 65% of the potential transit demand if the walking distance to reach a bus stop is discarded. However, if we consider 500 metres as an acceptable distance required to reach the bus stops, the demand is met at 37%

This low service performance is to the result of the deficiencies of public transport route coverage as well as capacity constraints. In fact, a better access to public transport service is only observed nearby the main city hubs, considering that the high network density and high route overlap are observed in these areas. There is an insufficient of public transport service in most road segments (i.e. 67% of road segments). However, the results show that offered service capacity outstrips considerably the demand in some road segments. This indicates the inadequate planning in allocating bus to routes and indicates how the public transport sector is still informal in Kigali, considering that most buses are operated by individual operators with different bus sizes.

Based on the results, we have identified what should be improved to ultimately provide a better public transport service. One of the suggested improvements is to extend the coverage of public transport system. Along this, we identified suitable roads for public transport network expansion. To address the insufficiency of public transport service, we suggested the provision of larger buses, and increase of service frequency in bus lines with high headway. We have also identified priority bus lines that should be allocated larger buses based on their observed headways.

On other hand, the level of performance depends on the threshold used. Since there is no specific standard for bus service performance assessment in Rwanda, we identified performance indicators which are generally applicable in developing countries. By then, the developed measurements offer the possibility to consider different thresholds. For instance, if we consider 1000 metres as an acceptable distance required to reach the bus stops, the demand is met at 55%. The same alterations can be applied by changing either the acceptable waiting time or service span. This would help decision makers to objectively assess the performance and make better decisions regarding the allocation of public transport service.

The adopted performance measurement provides valuable insights of where and how much public transport services are needed in Kigali City, and proves to be a valuable analysis measure to evaluate overall service performance. However, an integration of time-of-day based demand would offer more plausible understanding of service availability based on time of the day, and this can be explored in future researches.

7.2. Recommendations

On the basis of gathered data and based upon the observations and the undertaken service performance assessment, we advocate the following recommendations:

- The undertaken analysis considered only the working days. Since the characteristics of week-end days and normal working days vary considerably in Kigali, further research would assess the service performance in week-end days as well.
- Our analysis relied on the estimated potential transit demand per day. However, the transit demand is time-dependent, and varies with the time of the day (peak/off-peak period). The determination of detailed OD according to the time periods is recommended for further research. Detailed OD matrices should provide data according to uniform demand time periods, and a good representation should be based on a survey in which passengers are asked directly about their precise origin and destination (Ceder, 2007).
- The research suggested the extension of public transport network coverage. A study on the optimization of bus routes (including bus stops) throughout the city of Kigali is recommended, considering that matching supply to demand through design of the appropriate bus route network structure would improve the access to the public transport service.
- The analysis of public transport service capacity reveals a considerable variability of service provision between different bus route segments. At some extent, this reflects inadequate planning in public transport service provision. On other hand this variability would be explained by the fact that in general operators prefer paved roads over the unpaved ones (Iles, 2005). Moreover, a number of roads are narrow for effective car traffic, and this could restrain larger buses to operate in those roads. Therefore, the extension as well as the rehabilitation of existing bus routes is recommended.
- This study explored one component, service supply, among the most two concern component of passenger perspective in regards to the public transport performance. A study on comfort and service convenience could provide a more deep insight on performance of public transport system in Kigali.

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Appendices

Appendix 1: Bus line names

Bus line ID	Bus line name
1	City_Gikondo_1
2	City_Gikondo_2
3	City_Gisozi
4	City_Kacyiru
5	City_Kagugu
6	City_Kicukiro_1
7	City_Kicukiro_2
8	City_Kimironko
9	City_Kinyinya
10	City_Nyabugogo
11	City_Nyamirambo_I
12	City_Nyamirambo_II_2
13	City_Remera
14	Continu
15	Karuruma_Nyacyonga
16	Kicukiro_Gahanga
17	Kimironko_Zindiro
18	Nyabugogo_Gikondo_1
19	Nyabugogo_Gikondo_2
20	Nyabugogo_Giticyinyoni
21	Nyabugogo_Kagugu
22	Nyabugogo_Karuruma
23	Nyabugogo_Kicukiro_1
24	Nyabugogo_Kicukiro_2
25	Nyabugogo_Kimironko
26	Nyabugogo_Nyamirambo
27	Nyabugogo_Remera_I
28	Nyabugogo_Remera_II
29	Nyamirambo_butamwa
30	Remera_Gikondo
31	Remera_Kabuga
32	Remera_Kanombe
33	Remera_Kicukiro
34	Remera_Masaka
35	Remera_Rubirizi
36	ULK_Kagugu

Terminology:

X_Y: The direction from X to Y and Y to X use the same bus line

X_Y_1: Bus line exclusively for the direction X to Y

X_Y_2: Bus line exclusively for the direction Y to X

X_Y_I: First route connecting X and Y

X_Y_II: Second route connecting X and Y

X_Y_II_2: Bus line exclusively for the direction Y to X of the second route connecting X and Y

Bus route: a bus route simply refers to the link between two end-terminals; a bus route may have two lines representing the two adverse directions.

Bus line: a bus line here refers to the infrastructure (i.e. a road in real world) or alignment traveled by a bus

Appendix 2: Section attributes table (SEC)

Arc ID	Bus line ID
2	1
33	1
39	1
40	1
41	1
2	2
3	2
4	2
30	2
33	2
40	2
48	2
22	3
24	3
25	3
26	3
31	3
32	3
33	3
30	4
33	4
35	4
76	4
22	5
24	5
27	5
28	5
29	5
31	5
32	5
33	5
3	6
4	6
30	6
44	6
46	6
65	6
66	6

Arc ID	Bus line ID
3	7
4	7
30	7
43	7
44	7
45	7
65	7
66	7
1	8
30	8
33	8
34	8
36	8
37	8
76	8
78	8
16	9
17	9
18	9
19	9
30	9
33	9
34	9
76	9
31	10
32	10
54	10
62	10
64	10
65	10
66	10
49	11
50	11
51	11
52	11
75	11
33	12
50	12

Arc ID	Bus line ID
51	12
52	12
68	12
70	12
71	12
2	13
3	13
4	13
5	13
6	13
7	13
9	13
30	13
33	13
44	13
45	13
63	14
68	14
69	14
70	14
75	14
55	15
47	16
36	17
37	17
73	17
20	18
38	18
40	18
41	18
42	18
4	19
20	19
38	19
40	19
48	19
56	20
57	20

Arc ID	Bus line ID
59	20
20	21
21	21
22	21
27	21
28	21
29	21
57	22
58	22
4	23
20	23
38	23
44	23
46	23
4	24
20	24
38	24
43	24
44	24
45	24
1	25
20	25
21	25
22	25
23	25
34	25
35	25
36	25
37	25
78	25
52	26
53	26
56	26
57	26
4	27
5	27
6	27
7	27

Arc ID	Bus line ID
9	27
20	27
38	27
44	27
45	27
1	28
7	28
9	28
20	28
21	28
22	28
23	28
34	28

Arc ID	Bus line ID
35	28
61	28
60	29
72	29
5	30
6	30
7	30
9	30
40	30
44	30
45	30
48	30
8	31

Arc ID	Bus line ID
9	31
10	31
13	31
14	31
79	31
8	32
9	32
10	32
11	32
12	32
5	33
6	33
7	33

Arc ID	Bus line ID
9	33
43	33
8	34
9	34
10	34
13	34
15	34
79	34
9	35
77	35
29	36
74	36

Appendix 3: Load profile density of road segments

Arc ID	Load profile density
1	1.00
2	1.00
3	1.00
4	0.97
5	1.00
6	0.99
7	1.00
8	1.00
9	1.00
10	1.00
11	1.00
12	0.65
13	1.00
14	0.78
15	0.80
16	0.67
17	1.00
18	1.00
19	0.84
20	0.91
21	1.00
22	1.00
23	0.92
24	1.00
25	1.00
26	0.77
27	1.00
28	0.90
29	0.87
30	1.00
31	1.00
32	1.00
33	1.00
34	1.00
35	0.89
36	1.00
37	0.70
38	0.93
39	0.55
40	0.89
41	0.98
42	1.00
43	0.68
44	1.00
45	0.98
46	0.73
47	0.61
48	0.98
49	1.00
50	0.81
51	1.00
52	1.00
53	0.80
54	0.81
55	0.52
56	1.00
57	1.00
58	0.66
59	0.56
60	0.56
61	1.00
62	1.00
63	1.00
64	1.00
65	1.00
66	1.00
68	1.00
69	1.00
70	1.00
71	1.00
72	0.00
73	1.00
74	0.49
75	0.65
76	0.93
77	0.49
78	0.81
79	0.73

Appendix 4: Flowmap modelling results

Exploration doubly constrained model
01-20-2012 11:02:47
Model parameters:
Model type: Doubly constrained
Distance decay: Exponential Function
Origin attractions/constraints: SUM_ORG_B
Destination attractions/constraints: SUM_DEST_B
Convergence criterion: 1%

Model Iteration 1:
Beta value: 0
Balancing factors have converged; calculating (ln)MTL
Estimated Mean Trip Length: 2292.9650(7.6000060)
Beta * Mean Trip Length: 0

Model Iteration 2:
Beta value: 0.0001013
Balancing factors have converged; calculating (ln)MTL
Estimated Mean Trip Length: 2254.9580(7.5791830)
Beta * Mean Trip Length: 0.2283823

Model Iteration 3:
Beta value: 0.0004051
Balancing factors have converged; calculating (ln)MTL
Estimated Mean Trip Length: 2136.50(7.5126730)
Beta * Mean Trip Length: 0.8655390

Model Iteration 4:
Beta value: 0.0009115
Balancing factors have converged; calculating (ln)MTL
Estimated Mean Trip Length: 1939.190(7.3920350)
Beta * Mean Trip Length: 1.7676110

Model Iteration 5:
Beta value: 0.0016205
Balancing factors have converged; calculating (ln)MTL
Estimated Mean Trip Length: 1691.4050(7.2023460)
Beta * Mean Trip Length: 2.7408890

Model Iteration 6:
Beta value: 0.0025320
Balancing factors have converged; calculating (ln)MTL
Estimated Mean Trip Length: 1460.6640(6.9695670)
Beta * Mean Trip Length: 3.6984030
Model Iteration 7:
Beta value: 0.0036461
Balancing factors have converged; calculating (ln)MTL
Estimated Mean Trip Length: 1306.3410(6.7762660)
Beta * Mean Trip Length: 4.7630250

Model Iteration 8:
Beta value: 0.0049627
Balancing factors have converged; calculating (ln)MTL
Estimated Mean Trip Length: 1220.0660(6.6468420)
Beta * Mean Trip Length: 6.0548480

Model Iteration 9:
Beta value: 0.0064819
Balancing factors have converged; calculating (ln)MTL
Estimated Mean Trip Length: 1171.0380(6.5602510)
Beta * Mean Trip Length: 7.5905760

Model Iteration 10:
Beta value: 0.0082037
Balancing factors have converged; calculating (ln)MTL
Estimated Mean Trip Length: 1141.4390(6.5001130)
Beta * Mean Trip Length: 9.3640050

Model Iteration 11:
Beta value: 0.0101280
Balancing factors have converged; calculating (ln)MTL
Estimated Mean Trip Length: 1122.8640(6.4577650)
Beta * Mean Trip Length: 11.372370

Model Iteration 12:
Beta value: 0.0122549
Balancing factors have converged; calculating (ln)MTL
Estimated Mean Trip Length: 1111.3070(6.4282860)
Beta * Mean Trip Length: 13.618940

Model Iteration 13:
Beta value: 0.0145843
Balancing factors have converged; calculating (ln)MTL
Estimated Mean Trip Length: 1104.1120(6.407740)
Beta * Mean Trip Length: 16.102730

Model Iteration 14:
Beta value: 0.0171163
Balancing factors have converged; calculating (ln)MTL
Estimated Mean Trip Length: 1099.4340(6.3929070)
Beta * Mean Trip Length: 18.818270

Model Iteration 15:
Beta value: 0.0198509

Further exploration impossible

Doubly constrained gravity model
01-23-2012 09:17:59
Model parameters:
Model type: Doubly constrained
Distance decay: Exponential Function
Origin attractions/constraints: SUM_ORG_B
Destination attractions/constraints: SUM_DEST_B
Convergence criterion: 1%

Model Iteration 1:
Beta value: 0.0009096
Target Mean Trip Length: 1099.4340
Target Log Mean Trip Length: 7.0025510
Balancing factors have converged; calculating (ln)MTL
Estimated Mean Trip Length: 1939.8880
Remaining deviation (abs): 840.45360
Remaining deviation (%): 76.444210

Model Iteration 2:
Beta value: 0.0016049
Target Mean Trip Length: 1099.4340
Target Log Mean Trip Length: 7.0025510
Balancing factors have converged; calculating (ln)MTL
Estimated Mean Trip Length: 1696.2770
Remaining deviation (abs): 596.84270
Remaining deviation (%): 54.286360

Model Iteration 3:
Beta value: 0.0033085
Target Mean Trip Length: 1099.4340
Target Log Mean Trip Length: 7.0025510
Balancing factors have converged; calculating (ln)MTL
Estimated Mean Trip Length: 1341.9520
Remaining deviation (abs): 242.51810
Remaining deviation (%): 22.058450

Model Iteration 4:
Beta value: 0.0044745
Target Mean Trip Length: 1099.4340
Target Log Mean Trip Length: 7.0025510
Balancing factors have converged; calculating (ln)MTL
Estimated Mean Trip Length: 1244.8890
Remaining deviation (abs): 145.45520
Remaining deviation (%): 13.230010

Model Iteration 5:
Beta value: 0.0062218
Target Mean Trip Length: 1099.4340
Target Log Mean Trip Length: 7.0025510
Balancing factors have converged; calculating (ln)MTL
Estimated Mean Trip Length: 1177.3210
Remaining deviation (abs): 77.887080
Remaining deviation (%): 7.084290

Model Iteration 6:
Beta value: 0.0082360
Target Mean Trip Length: 1099.4340
Target Log Mean Trip Length: 7.0025510
Balancing factors have converged; calculating (ln)MTL
Estimated Mean Trip Length: 1141.030
Remaining deviation (abs): 41.595830
Remaining deviation (%): 3.7833860

Model Iteration 7:
Beta value: 0.0105446
Target Mean Trip Length: 1099.4340
Target Log Mean Trip Length: 7.0025510
Balancing factors have converged; calculating (ln)MTL
Estimated Mean Trip Length: 1120.0840
Remaining deviation (abs): 20.649780
Remaining deviation (%): 1.8782190

Model Iteration 8:
Beta value: 0.0128206
Target Mean Trip Length: 1099.4340
Target Log Mean Trip Length: 7.0025510
Balancing factors have converged; calculating (ln)MTL
Estimated Mean Trip Length: 1109.2170
Remaining deviation (abs): 9.7834470
Remaining deviation (%): 0.8898622

Calibration completed successfully!

Appendix 5: Set up of suitability analysis for PT route extension