Master's Thesis of Engineering

Gravity-Based Accessibility Indexes for Evaluating Impacts of Transportation Projects using GIS: Method and Application to City of Kinshasa

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Abstract

Gravity–Based Accessibility Indexes for Evaluating Impacts of Transportation Projects using GIS: Method and Application to City of Kinshasa

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This research proposes an accessibility oriented method for evaluating impacts of transportation improvement projects based on accessibility performance indexes developed using gravity–based accessibility model. An analysis tool combing GIS and EMME3 was built for applying the proposed method to a practical case of Kinshasa city in order to show its usefulness and applicability in solving problems and reaching planning goals. Impacts of two proposed major road infrastructure improvement projects on accessibility to jobs are evaluated, using data collected from government agencies and other sources. Finally, the developed accessibility indexes are used to identify scenarios that improve mobility and best increase the accessibility of less accessible zones. Results of this case study show a consistency with previous studies and the theory of gravity based accessibility in addition to solve the problem of analyzing both mobility and accessibility solutions at the same time. However, further research is needed to consider more precise units such generalized cost

instead of travel time cost; and also to consider other options such as various transport modes and planning of new land use pattern.

Keyword: Accessibility, GIS, accessibility measures, gravity-based accessibility, Mobility

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Chapter 1. Introduction

1.1. Research Background

Conventional transportation planning has been focusing on mobility, which consist of evaluating transport system performance based on quantity and quality of physical travel. While still focusing on the mobility, a shift occurred from strategies to increase infrastructure capacity for automobile traffic to broader policies with environmental and social dimensions (Ahmed El-Geneidy, 2011).

Recent research indicates that a paradigm shift is occurring in transportation planning. It is described as a shift from mobility-oriented analysis to accessibility-based analysis (which considers a broader range of impacts and options) (Litman, Evaluating Accessibility for Transportation Planning, 2011). This is in part because the accessibility-based analysis is considered superior to mobility-based analysis in that it tends to consider other factors, and so favors different solutions, including improvements to alternative modes, incentives to change travel behavior, and more accessible land use patterns (Litman, Evaluating Accessibility for Transportation Planning, 2011) .

Moreover, accessibility can be evaluated from various perspectives, including a particular group, mode, location or activity while the conventional planning tends to overlook and undervalue some of these factors and perspectives. A more comprehensive analysis of accessibility in planning expands the scope of potential solutions to transport problems (Litman, Evaluating Accessibility for Transportation Planning, 2011).

It is also well recognized in the academic field that area with better access to the locations of input materials and markets will be more productive, more competitive and hence more attractive than remote and isolated areas (Coppola, 2012).

In real world, the access is provided by the available transportation systems. Thus, there is evidence that any changes in the transportation systems will impact on the spatial development and vice versa. In this context therefore, the consideration of modeling analysis such as those based on accessibility measures, becomes necessary to investigate the impacts of transportation systems improvement on the spatially distributed patterns.

In the case study of Kinshasa, the accessibility oriented approach is proposed because of the wide range of possible solutions it offers, given the nature of the problem.

In fact, the city being mono-centric in terms of activities such as employments, shopping centers, etc. and considering the fast growing of population and urban sprawls, the extension of population far from the activity centers, and the increasing traffic congestions, both the mobility and access to activities are reduced.

According to a recent study on the mobility of Kinshasa (Transurb Technirail, 2011), in terms of mobility, the position of the unique city center of activities prevents any form of consistent solution to transportation problems, as the pressure on the only urban center generates traffic congestions on all radial roads. Thus, the mobility analysis approach itself has filled to provide a consistent solution.

As an alternative solution to these problems, it was suggested to apply land use planning solutions which will consist of decentralizing or delocalizing some activities from city center to the east of the city in order to provide more access to activities.

A set of solutions was also proposed for improving the mobility, including infrastructure improvement projects, development of mass transit systems such as BRT, etc. The goal is therefore to plan for more accessible activities or land use patterns while also planning for the mobility.

However, the problem remains to find a method for evaluating the impacts of the proposed solutions in order to investigate whether they reach the goals so that they can be classified by priority.

Therefore, this study proposes an accessibility oriented analysis approach and performance measures to solve this problem.

Using the accessibility as approach may give more control over the problem and provide a wide range of solutions and a way of evaluating them. For example, using the accessibility-based analysis, the mobility-based solutions can be tested and in case of limitation, other alternatives such as the decentralization or delocalization of activities can also be tested and the benefit in terms of both mobility and accessibility gained by each zones can be assessed and planning for more balanced accessibility.

Accessibility has an advantage on mobility in this aspect since it investigates both the land use and transportation component of the proposed solutions.

1.2. Research Purpose and Contribution

The Accessibility Based Analysis approach is widely recognized for its robustness. However, the gap between the theory of accessibility measurement and its practical application in a way that is useful to planners in achieving goals needs to be bridged.

Also, the definition of goals often leads to a need for performance measures to monitor progress toward their attainment (Briassoulis, 2001)

Therefore, the purpose of this research is to develop useful accessibility performance measures that aim at monitoring progress toward the goals of increasing the accessibility of less accessible zones, by evaluating and identifying projects that best reach these goals.

It also aims at providing a practical application through a study on the city of Kinshasa, to show the usefulness and applicability of the developed tool in solving problems and reaching planning goals.

1.3. Research Composition

Literature Review

- Mobility Oriented Analysis Vs. Accessibility Oriented Analysis
- Accessibility Models and Measures

⇩

Data Collection

- Travel Demand Forecasting Data
- Accessibility Estimation Data

⇩

Research Methodology

- Analysis Tools and Database
- Analysis Outline

⇩

Practical Case of Kinshasa

- Construction of Relevant Transportation Database.
- Analysis
- Accessibility Estimation

⇩

Discussion

- Interpretation of Results
- Consistency of results

⇩

Conclusion and Further Research

Chapter 2. Literature Review

First models of accessibility appeared in the late 1950s (Hansen, 1959). Since then, many researchers have developed the concept further. A number of review studies classify and evaluate accessibility measures according to various criteria while others compare it with other transportation evaluation methods such as those based on mobility. The first part of this chapter compares the mobility oriented transportation evaluation perspective to accessibility oriented evaluation perspective. The second part will discuss and compare different accessibility models and measures.

2.1 Mobility Oriented Analysis vs. Accessibility Oriented Analysis

This section briefly compares the concepts of mobility and accessibility from various studies. Mainly it focuses on studies by Litman 2003, 2011 and 2016, which summarize and compare these two perspectives.

The accessibility refers to the ease of reaching opportunities such as goods, services, activities and destinations. To that extent, access is the goal of most transport activities.

On the other hand, mobility refers to physical movement, measured by trips, distance and speed, such as person-miles or kilometers for personal travel, and ton-miles or tonne-kilometers for freight travel.

Transportation evaluation practices are often based on three approaches which are the Vehicle travel, mobility and accessibility. The way that transportation is evaluated also affects planning decision.

For instance, if transportation is evaluated based on vehicle travel conditions, the only way to improve transport system quality is to improve roadways. If transportation is evaluated based on mobility, then rideshare and public transit service improvements can also be considered. If transportation is evaluated based on accessibility, additional transportation improvement options can be considered (besides roadway, rideshare and public transit), including improved walking and cycling conditions, more accessible land use patterns to reduce travel distances, and telecommunications and delivery services that substitute for physical travel. This solution offers many additional benefits, including infrastructure cost savings (reduced road and parking requirements), user cost savings, reduced pollution emissions, and increased fitness and health.

<Table 1> Transportation Evaluation Perspectives (Litman, Measuring Transportation: Traffic, Mobility and Accessibility, 2003)

	Vehicle Travel	Mobility	Accessibility
Definition of Transportation	Vehicle travel	Person and goods movement	Ability to obtain goods, services and activities
Measurement units	Vehicle miles	Person−miles and ton−miles	Trips, generalized costs
Modes considered	Automobile and truck	Automobile, truck and transit	Automobile, truck, transit, cycling and walking
Common indicators	Vehicle traffic volumes and speeds, roadway Level of Service, costs	Travel distance and speeds, road and transit Level of	Quality of available transportation choices. Distribution of destinations.

	per vehicle mile, parking convenience	Service, cost per person mile, travel convenience	Cost per trip
Consumer benefits considered	Maximum motor vehicle travel and speed	Maximum personal travel and goods movement	Maximum transport choice and cost efficiency
Consideration of land use	Treats land use as an input, unaffected by transportation decisions	Recognizes that land use can affect travel choice	Recognizes that land use has major impacts on transportation
Favored transportation improvement strategies	Roadway and parking facility improvements to increase capacity, speed and safety	Transportation system improvements that increase capacity, speeds and safety	Management strategies and improvements that increase transport system efficiency and safety
Transportation Demand Management (TDM)	Generally considers vehicle travel reductions undesirable	Generally considers vehicle travel reductions undesirable	Generally considers vehicle travel reductions undesirable

Therefore, in the case study of Kinshasa, the accessibility oriented approach is proposed because of the wide range of possible solutions it offers, given the nature of the problem and also to overcome the limitation of the mobility analysis solution.

2.2. Accessibility Models and Measures

2.1.1. Review on Accessibility Measures

Several definitions and related measures of accessibility are found in the literature. The accessibility may refer to the ability to reach desired goods, services, activities and destinations. It typically measures "the ease and convenience of access to spatially distributed opportunities with a choice of travel" (U.S. Department of Environment, 1996).

Another definition proposed by the Swedish National Road Administration defines the accessibility as "the simplicity with which activities in the society can be reached, including needs of citizens, trade and industries and public services" (National Road Administration, 1998 page 2).

There are several measures of accessibility described in the literature. Some of important measures selected and explained in the following section include the distance measures, Cumulative-Opportunity Measures, Utility Based Measures, and Gravity Based measures.

Distance measures are one of the simplest measures of accessibility in which the distance from one location to different opportunities can be measured in multiple ways including the average distance, weighted area distance or distance to the closest opportunity, estimated from simple straight-line distances to more complicated impedance formulations (Carolin Folkesson). The choice on the measure of distance to be used is also an important factor to consider while analyzing the accessibility. For example, the accessibility measured by average distance does not consider the attractiveness of destinations as it simply estimates the average distance to all destinations from one departure point or zone and vice versa. Weighted average distance on the other hand makes up for this draw back by considering the attractiveness of the destination through measures such as the "shortest distance"

Wachs and Kumagai (1973) proposed other measures of accessibility referred to cumulative-opportunity measures which consist in evaluating the accessibility with regard to the number or proportion of opportunities within certain travel distance or time from a given location. These measures take into account the various choices available to residents within an area. They involve the calculation of the cumulative index by weighting all potential destinations within the cut-off area equally.

This index may also take into consideration the spatial distribution of opportunities. The calibration of cumulative measures is a crucial factor for the accessibility levels are very sensitive to the cut-off travel distance or time calculated during this (the calibration) process. Cumulative measures may be easy to calculate but they entail a somewhat arbitrary calibration (Carolin Folkesson).

Utility-Based Measures are based on random utility theory, which assumes that individuals maximize their utility, meaning that they give each destination a utility value, and that the likelihood of an individual choosing a particular destination depends on the utility of that choice compared to the utility of all other choices.

The utility function reflects the attractiveness of the destination, the travel impedance, and the socio-economic characteristics of the individual or household captured by its variables (Carolin Folkesson).

Accessibility A_n for individual n can be measured as:

$$A_n = ln\left(\sum_{\forall \in C} \exp\left(U_{n(c)}\right)\right)$$

, where $U_{n(c)}$ is the observable temporal and spatial transportation components of indirect utility of choice c for person n , C_n is the choice set for person n.

Gravity-based measures were developed to model the spatial distribution of trips between origins and destinations (Geertman and van Eck, 1995; Sonesson, 1998). They derive from the denominator of the gravity model for trip distribution and were justified in the analogy to a law of physics. Several types of gravity-based accessibility can be found in the literature. They briefly described in this section.

The "active accessibility" referred to proxy for the ease of zone i to reach the activities/opportunities located in different zones j of the study area for a given purpose moving from i (Coppola, 2012). It is estimated as follows:

$$A_{act,i} = \sum_j (wj) f(cij)$$

Where Wj is the activity or opportunity to reach in zone j, and cij is the generalized costs of reaching zone j from zone i.

On the other hand, the "passive accessibility" is a proxy of the opportunity of an activity located in a given zone I to be reached from the potential "consumers" coming from all the other zones j of the study area for a given purpose. It is estimated as follows:

$$A_{pas,i} = \sum_j (wj) f(cji)$$

Where Wj are the potential consumers of the activity or opportunity to be reached in the zone i, and c_{ji} is the cost of reaching zone i from zone j.

These previous two types of accessibility can be considered as particular cases of the "relative accessibility" A_{ij} at location i, defined as the attraction at destination j discounted by the distance decay function between these two points. It is estimated as following:

$$A_{ij} = \sum_j (wj) f(C_{ij})$$

The function C_{ij} is the distance decay function component of the gravity model and represents the deterrence or impedance to travel or interaction between locations due to distance, when all other determinants of interaction are held constant (Fotheringham, 1981).

The most recent use of gravity-based accessibility model considers the accessibility of a given zone as a sum of the generalized travel costs between the zone itself and other zones of the study area weighted by an attraction term representing the opportunities to be reached in the other zones. It is calculated as following:

$$A_i = \sum_{j=1}^{n} W_j \, e^{-\beta c_{ij}}$$

, where A_i is the accessibility of zone i, W_j the activity or opportunity to reach in zone j, C_{ij} is the travel cost of reaching zone j from zone i, β the travel impedance parameter and n is the number of zones.

In this model, the agglomeration effects is taken into account through weighted values W_j, whereas the impendence function, $f(c_{ij}) = e^{-\beta c_{ij}}$, typically includes the travel time in a negative exponential form, based on the assumptions that the attraction of a destination increases with size and declines with distance or travel time or cost .

The effects of changes in the transportation systems can be captured by means of the function $f(c_{ij})$ and changes in land use can be captured by means of the weights W_{ij}.

Gravity-based accessibility indicators are considered to be more powerful than travel time accessibility indicators and daily accessibility indicators; moreover, they are founded on sound and consolidated behavioral principles of the Random Utility Maximization (Ben-Akiva and Lerman, 1985).

2.1.2. Comparison of Accessibility Measures

<Table 2>Comparison of Accessibility Measures

Accessibility Measures	Advantage	Disadvantage
Distance Measures	- Simple to use - Can be measured in many ways	Some measures do not consider the attractiveness and impedance.
Cumulative-opportunity Measures	- Easy to calculate - Consider the various choices available	Arbitrary calibration of the impedance
Gravity-based Measures	- Consider both Land-use effects and transportation effects - Consider the travel impedance and attractiveness - Flexible	Difficult to measure when all effects must be considered
Utility-based Measures	-Consider the attractiveness, travel impedance and socio-economic characteristics of the individual or household	Difficult to measure when all effects must be considered.

Therefore, in this research, the gravity based accessibility is used as methodology for its flexibility and its advantages over others measurements as described above.

Chapter 3. Data Collection

The methodology used in this study combines the traditional four steps travel demand forecasting and the gravity based accessibility models, applied to the case of Kinshasa city. Therefore, data required for the analysis had to be collected and treated for its use in the analysis. This chapter describes main data used in this study and their sources.

3.1. Travel Demand Forecasting Data

The basic components of the forecasting model are the transportation network, socioeconomic and Land Use data. This section describes the data needed and some sources for such data. It reviews the types of information that was necessary and the ways of obtaining it. Significant details on ways to build the needed databases can be found in the chapter 5.

3.1.1. Socioeconomic and Land Use Data

The trip generation equations require socioeconomic and land-use data to describe the quantity and type of travel activity in the region. Required land-use data include the number of households by size, household income or auto ownership, and employment by type.

In the case study of Kinshasa, the socioeconomic and land use data were gathered from various official sources and project reports. The majority of them came from government agencies such as the National Institute of Statistics, BEAU (Bureau d'Etude d'Amenagement Urbain), and the ministry of transportation.

Data on the travel behavior were extracted from the 1991 household survey report and updates of recent surveys.

These data are summarizing in the following table:

<Table 3>Socioeconomic and land use data and sources

Data	Source
Population	National institute of statistics (Plan, 2005) (Bienvenu Bolia Ikoli, 2014)
Habitat types (income level)	1991 Household survey and recent update from BEAU (BECEOM, Juin 1994)
Average number of persons in household by zone types	National institute of statistics (BECEOM, Juin 1994)
Mode of travel to work and other purposes	1991 Household survey report and 2011 survey (BECEOM, Juin 1994) (Transurb Technirail, 2011)
Average vehicle ownership rates by household	1991 Household survey report (BECEOM, Juin 1994)
Time of departure from work	1991 Household survey report (BECEOM, Juin 1994)
Travel Behavior data	1991 Household survey and recent studies (Transurb Technirail, 2011)
Traffic count data	2006 and 2011 surveys (Ministère des transports et communications, groupe d'études des transports, CIMA International, 2006)

3.1.2. Transportation Network Data

Different information and data on the road network were gathered from various sources for the construction of the base year network database. These information and data include the official inventory of the road network and their characteristics gathered from various project reports, official and third-party GIS database of the network and satellite image map services such as Google map, Bing map and Openstreet map. Sources and their use are summarized in the following table:

<Table 4>Transportation Network Data and sources

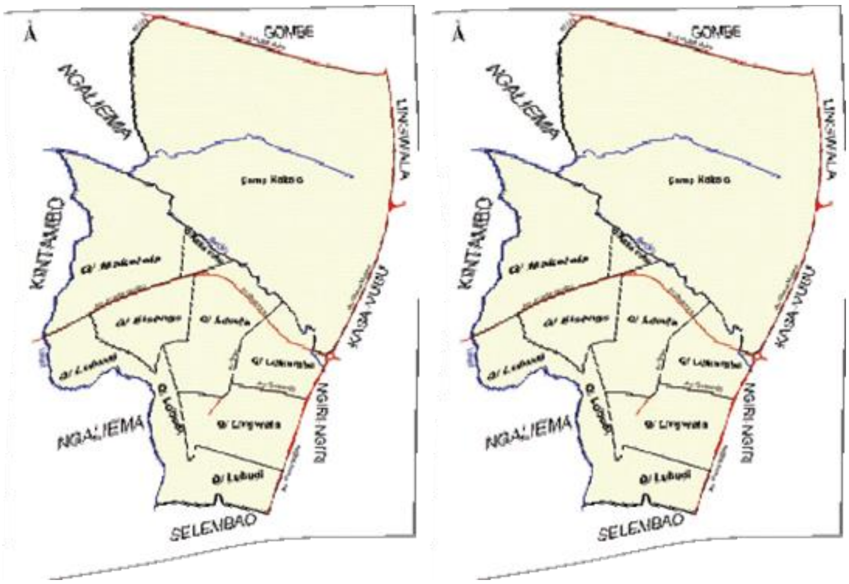
Source	Description	Type	Use
Office des routes (Government agency)	National road network (2009)	Shape File	Reference for the construction and validation of the base road network database
Cellule infrastructure (Government agency):	National road network (2012):	Shape File	Reference for the construction and validation of the base road network database
TRANSCO (Government agency):	Map of Bus Network of Kinshasa	Raster Image	Reference map for the Public Transportation base network database
Open street map (open source web mapping application):	Detailed Map of Road Network of Kinshasa (2016)	Shape File and satellite imagery	Main reference for the construction and validation of the base road network database
Bing map and Google map (web mapping applications)	Satellite map	Imagery	Validation of the base network

GET , BEAU, AGT (Government Agencies)	Official Transportation and Road Project Reports on Kinshasa	Soft and Hard Copies	In these reports information such as the road characteristics, number of lanes, design speed, length, function (primary, secondary), could be found

3.2. Accessibility Estimation Data

Throughout this study, the gravity based accessibility is used to evaluate the impact of proposed transportation projects at the quarter' s level. This involves the construction of a GIS database using maps in vector and raster or image formats, and the other data described in the previous section.

The vector maps include the transportation network maps detailed in the previous section and the city map of the 24 municipalities from the National Institute of Geography. Official vector maps of the quarter zones were not available at the period when this research was conducted. The only available maps of quarters were scanned image maps (Bienvenu Bolia Ikoli, 2014). Thus, the GIS software is used to build a vector map of all quarters (Smallest administrative division) based on the vector map of 24 zones and images of the quarters using the GIS geo-referencing method.



<Figure 1>Example of Images used for Georeferencing. Municipalities of Bandalungwa and Kasa-Vubu (Bienvenu Bolia Ikoli, 2014)

More details about the use of data described in this chapter are presented in the chapter 5, which deals with the construction of a relevant database for the case study.

Chapter 4. Research Methodology

This chapter describes the methodology used in this research. More details on sub steps can be found in the chapter 5.

4.1. Analysis Tools and Database

The aim of this study is to develop a simple and robust tool to evaluate the impacts of transportation improvement projects on the accessibility. This tool, viewed as a whole, is intended to accomplish two main functions. The estimation of travel cost using a transportation demand forecasting model; measuring the changes in accessibility levels brought about by different projects, and estimating and displaying the road conditions on road sections.

Therefore, a combination of two main analysis tools is used to achieve these functions; the Geographic Information System and Travel Demand Model. This combination will allow modeling both transport effects and spatial interactions between zones and computing the zonal accessibility level.

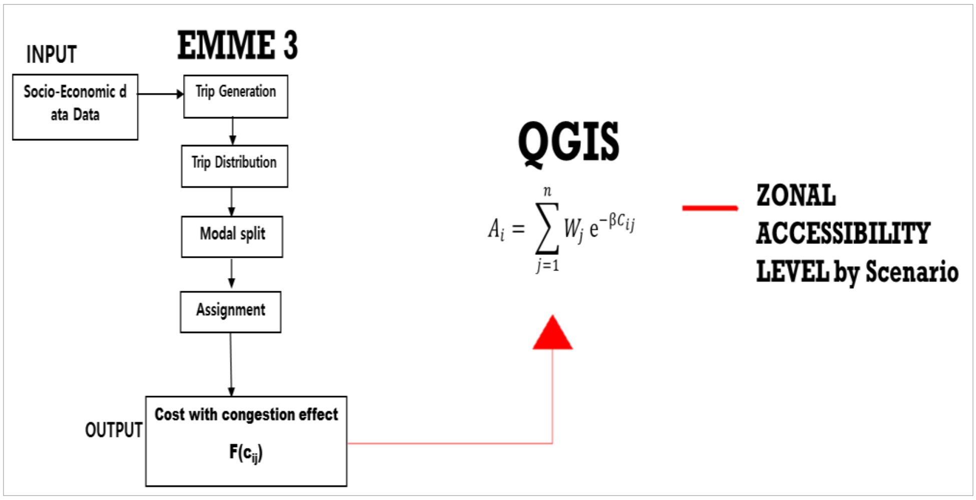
The GIS software QGIS is used to build the GIS database of the City of Kinshasa for the case study, including the transportation network, socio-economic and land-use data. It is also used for the estimation of accessibility by scenarios and displaying the road condition on different road sections as well as the accessibility level of each zone on the map.

The EMME 3 package is mainly used for the transportation demand modeling including the estimation of the travel cost matrix which is the main input for the estimation of the accessibility.

4.2. Analysis Outline

4.2.1. Travel Demand Forecasting Assumptions

The first step involves the estimation of the travel cost between quarters (TAZs). The objective is to capture the travel cost between zones resulting from the Travel Demand Analysis so that they can be used to estimate the accessibility level of each zone. By doing so, both the land-use and transportation system changes can be considered.



<Figure 2>Methodological Process

A transportation demand model of Kinshasa is first built for the base year. Using EMME 3, the conventional four steps of travel demand forecasting is performed to estimate the travel cost matrix.

Since the purpose is to estimate the accessibility to work, home-based work trips are modeled separately. Accessibility models often focus on work trips in part because work is an important travel generator and the majority of AM peak extra-zonal trips are home-work trips. Also, work activities are considered economically more important than other trips. Other trips are also considered separately to account for the congestion effects.

Only the auto mode is considered in this study. Other modes using the auto network are converted to auto equivalent in order to account for their effects in the traffic congestion.

Three scenarios are modeled, all of them being major road infrastructure improvement projects. In the first scenario, a set of road infrastructure improvement and new road construction projects is modeled. In the second scenario another set of projects is modeled. The purpose of these projects was to improve the North-South and East-West connections of the City of Kinshasa. Finally, in the last scenario, the two proposed sets of projected are also modeled.

Once the cost matrix is estimated, the gravity-based accessibility is then used to estimate the accessibility level for each quarter (TAZs).

Several accessibility indexes or performance measures are developed to evaluate the impacts of each scenario on the accessibility. That is, the changes in accessibility brought about by each proposed project. These accessibility indexes and the methodology for their estimation are described in this section.

4.2.2 Accessibility Estimation

The accessibility is measured here using the gravity-based accessibility calculated as following:

$$A_i = \sum_{j=1}^{n} W_j \, e^{-\beta c_{ij}}$$

where, A_i is the accessibility of zone i, W_j the activity or opportunity to reach in zone j, c_{ij} is the travel cost of reaching zone j from zone i,

β the travel impedance parameter and n is the number of zones or quarters.
Using the gravity based accessibility the level of accessibility of a given zone depends on two variables. The level of opportunities to the destinations in number of jobs and the travel cost between origin and destination zones i and j, weighted by the travel impedance parameter β.

Traffic congestion in transportation networks occurs as its use increases. It is characterized by slower speeds, longer trip times, and vehicular queuing which may affect the accessibility. Moreover, the travel time under congested flow conditions is the basic unit in the transportation system. Therefore, to be more concise and pragmatic, the congestion effects should be considered in the model. Specifically, in this research a Travel Demand Modeling is used for capturing the congestion effects.

The gravity-based accessibility weights the travel cost by a sensitivity parameter referred to the coefficient of conductance, beta (β), which express the willingness or tendency of individuals to bear a higher or lower travel cost. The value of β is obtained during the calibration of the gravity model and may be different for each trip purpose.

4.2.3 Accessibility indexes and Units

This section describes accessibility performance measures and units developed and used in this study.

Accessibility Index:

The Accessibility Index (AI) is a performance measure developed to present and compare the results in the easiest and meaningful way. It is the ratio between the result of the accessibility (A_i) and the total number of activities of the study area (W_i). Its maximum value is 1 since the number of opportunities reachable by a zone will never exceed the total number of opportunities in the region.

Unit of Travel Cost (Average Travel Time):

The travel cost expresses the cost required by people from a zone i to reach each of all opportunities accessible to them. The unit of cost used in this study is the average travel time from the origin zone i to all destinations. It was used as a performance measure for the mobility and to compare the change in the accessibility between different scenarios for each zone individually.

4.2.4 Accessibility Performance Measures for the whole Study Area

This section describes aggregated accessibility performance measures developed for assessing the change in the accessibility level for whole study area.

Average Accessibility Index (AAI):

The Average Accessibility Index is the average for all AI of all individual zones. It is used to present the accessibility level of the whole study area and also to compare different scenarios of proposed transportation plans.

Accessibility Gap:

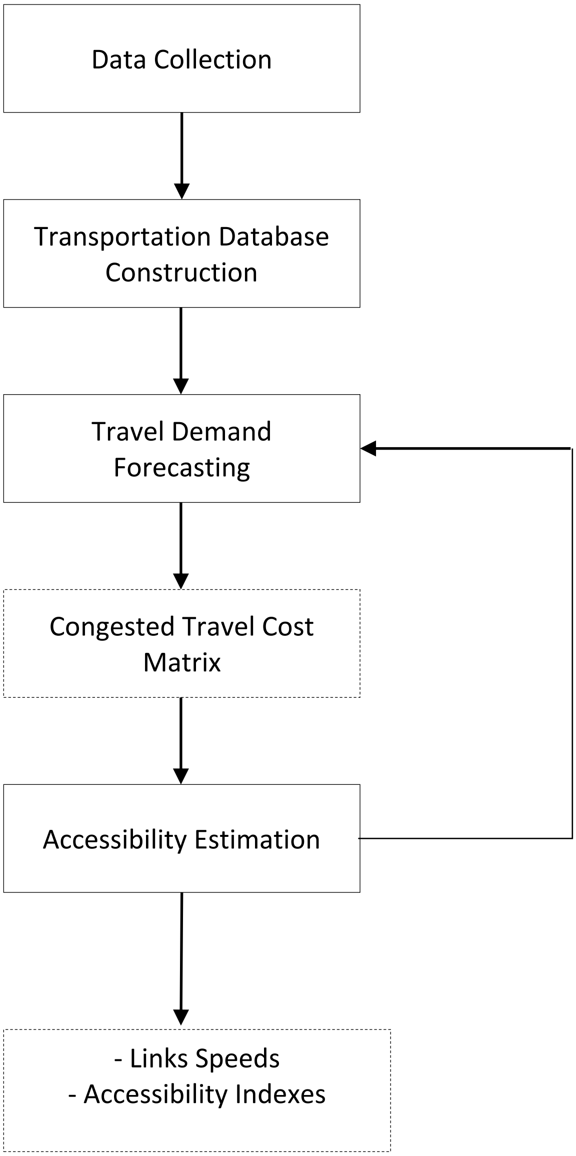
The accessibility gap is the difference between the accessibility index of the most accessible zone and the less one. It is useful for showing the accessibility variation in particularly because the average accessibility doesn' t provide an insight on the accessibility of the whole study area.

Total Average Travel Time:

The total average travel time is the average travel time of the region. To be more specific, it is the average of all average travel times between zones to all other zones. It is also used as a performance measure for the mobility to compare with the change in accessibility of the whole study area.

Using the above accessibility measures, the impacts of transportation on the accessibility can be assessed. The particularity of these measurements are that they can be used for planning for a balanced accessibility by prioritizing projects that increase the accessibility of less accessible zones.

<Figure 3>Process Summary



Chapter 5. Practical Case of Kinshasa

5.1. Overview

Throughout this study, the case study of the city of Kinshasa is used to illustrate the application of the proposed method. This chapter presents this case study in its entirety, including the database construction, travel demand modeling steps and the estimation of accessibility.

The main goal is to identify the project or set of projects that best increase the accessibility to employments for less accessible zones. This is done by evaluating the impacts of new infrastructure improvement projects on accessibility to the spatially distributed employments using the accessibility performance measures described in the previous section. The question is to know, how much the accessibility increases at each zone and in the whole city, when there is a change in the transportation system and which project or solution provide more benefit in terms of accessibility and mobility.

First, the base year accessibility levels of quarter zones are estimated under prevailing socio-economic and transportation systems conditions, then a set of future transportation projects are selected and applied to the transportation systems. Finally, the impacts and benefits of each individual projects are evaluated to identify the project that provide the highest benefit in terms of accessibility.

5.2. State of Art

5.2.1. Overview

The city-province of Kinshasa is the capital and the largest city of the Democratic Republic of Congo by population size and covers an area of 9,965 km^2. However, approximately 600 km^2 only is urbanized (De Saint Moulin, 2005). The estimated population was estimated approximately 400,000 inhabitants in 1960 and nearly more than 6 million inhabitants in 2008. The average annual population growth rate from the period from 1960 to 2003 was around 6.8 percent (Lelo Nzuzi, 2008).

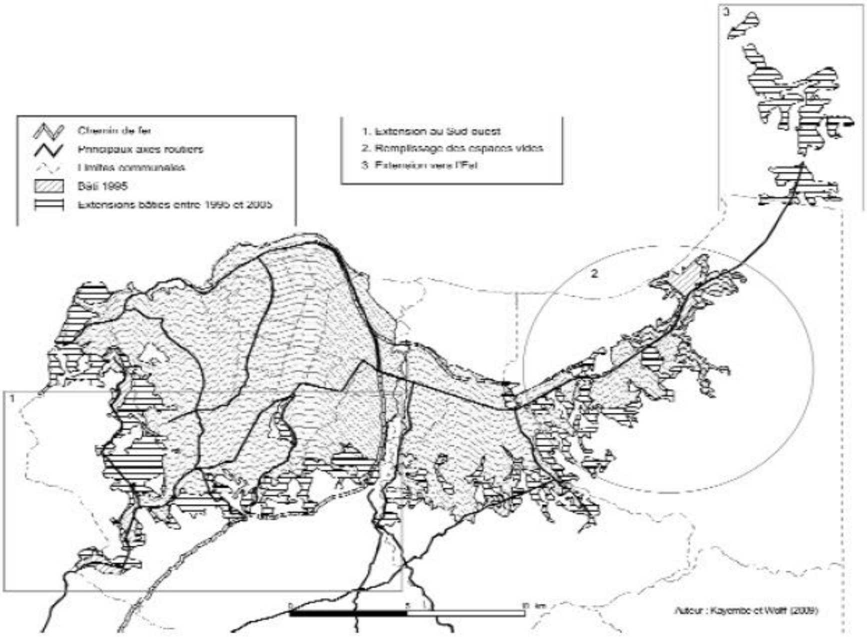
Moreover, the urban population in Kinshasa has increased by 34 percent in 10 years between 2001 and 2011. It is expected to have the highest urban population growth in Africa by 2025 (46 percent growth between 2010 and 2025) to reach almost 17 million people, surpassing Lagos and Cairo. If current trends continue, more than half of the urban population will be located in the eastern part of the city, dominated by the informal economy and urban agriculture of subsistence (Transurb Technirail, 2011).

<Table 5>Demographic and spatial evolution of Kinshasa

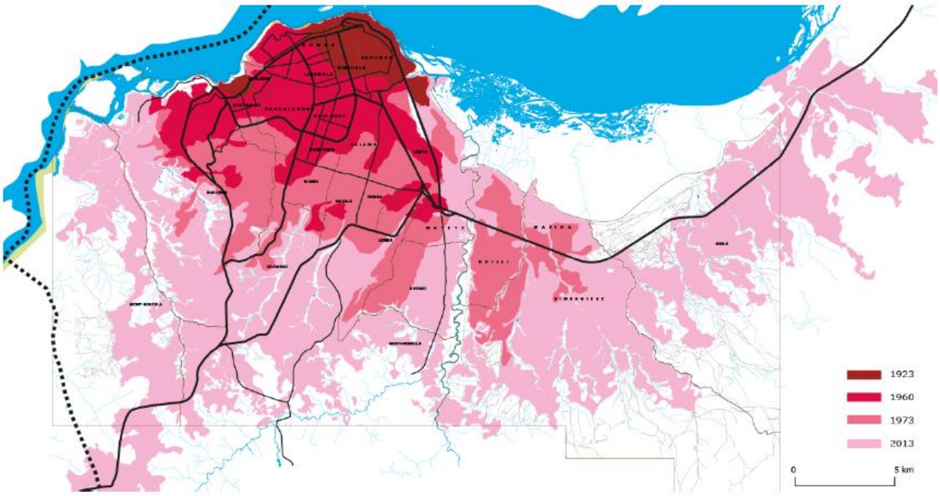
Year	Population	Area (ha)
1975	1 679 091	17 922
1981	2 567 166	20 160
1984	2 664 309	
1998	4 131 845	59 000
2000	6 500 000	60 000
2004	7 017 000	
2011	9 500 000	
2025	*17 000 000*	

The demographic and spatial growth of Kinshasa is mainly characterized by an informal urbanization. The lack of planning new urban areas and the renovation of existing ones has failed to stem the tendencies to sprawl and its consequences.

Factors characterizing this rapid urban growth include the over-densification of old and new towns (Habitat types) and the significant population growth in the east of the city in form of urban sprawl and far from the city center of economic activities. This causes spatial and economic imbalance between the mono-centric structure of the city which is focused around the CBD area and population density increasingly stronger in the east. At the same time, there is not sufficient employment hubs and adequate transportation infrastructure for the eastern part although its population exceeds that of the city center.



<Figure 4>Urban Sprawl in Kinshasa (Matthieu Kayembe Wa Kayembe M. D., Africa 2009)



<Figure 5>Growth of Urban Area of Kinshasa 1923-2013 (SOSAK, 2014)

5.2.2. Urban Growth and Transportation problems in Kinshasa

From a transportation point of view, this rapid growth of urban sprawl has negative impacts since it increases the need for public transport without considering the operating cost and profit or revenue. According to a recent study (Transurb Technirail, 2011), there is a risk that some areas will not be well served by public transport. In particularly because of non-profitability of the service due to high cost of accessing activity zones for the users in one part, and high operating cost for transit companies.

Another issue is that, if current trends continue, more than half of the urban population will be located in the eastern part of the city, dominated by the informal economy and urban agriculture of subsistence. If the city center remains as the unique center of activities including formal employment and administrative activities, this will result in increased traffic congestion between East and the CBD.

In summary, there are two main issues addressed here. The first one is related to the high traffic congestion experienced by the city center and its vicinity, due to the high demand and its attractiveness as the unique center of activities. The second problem is the difficulty of accessing formal jobs by the eastern population due to the high travel cost or the remoteness of the working zones which are concentrated around the CBD or center of activities.

According to a recent study on the mobility of Kinshasa (Transurb Technirail, 2011), in terms of mobility, the position of the unique city center of activities prevents any form of consistent solution to transportation problems, as the pressure on the only urban center generates congestion on all radial roads. Thus, the mobility analysis approach itself has filled to provide a consistent solution.

As an alternative solution to these problems, it was suggested to combine mobility solutions with land use planning solutions which will consist of decentralizing or delocalizing some activities from city center to the east of the city in order to provide more access to activities.

A set of solutions was also proposed for improving the mobility, including infrastructure improvement projects, development of mass transit systems such as BRT, etc. The goal is therefore to plan for more accessible activities or land use patterns while also planning for the mobility.

However, the problem remains to find a consistent method for evaluating impacts of the proposed solutions in order to investigate whether they reach the goals so that they can be classified by priority. To be more consistent and useful, such a method should be able to evaluate the changes in both accessibility and mobility brought about by the proposed solutions.

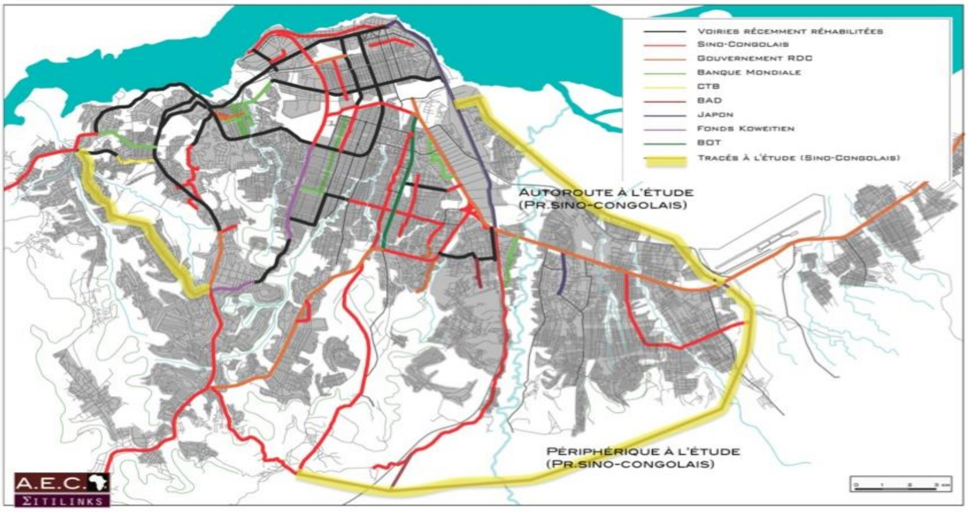
Thus, this study proposes an accessibility oriented analysis approach and performance measures to solve this problem. Accessibility approach has an advantage on mobility approach in this aspect since it investigates both the land use and transportation component of the proposed solutions. Its application to the city of Kinshasa is demonstrated in the following sections. Only solutions on improvement of road infrastructures were tested in this study.

5.3. Selected Transportation Projects

Project 1:

Project 1 is used as the first scenario in this study. It is a set of short term major road infrastructure improvement projects. They include projects on the rehabilitation and widening of existing roads, and the construction of new ones. Some of them were already completed in 2015. The targeted roads are the primary and secondary road classes.

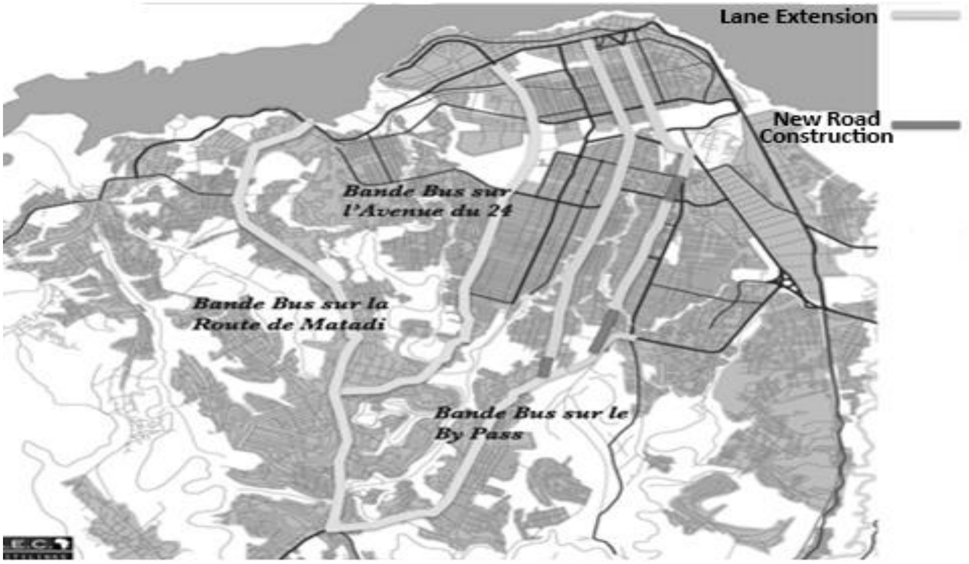
The map of these projects is shown in the following figure.



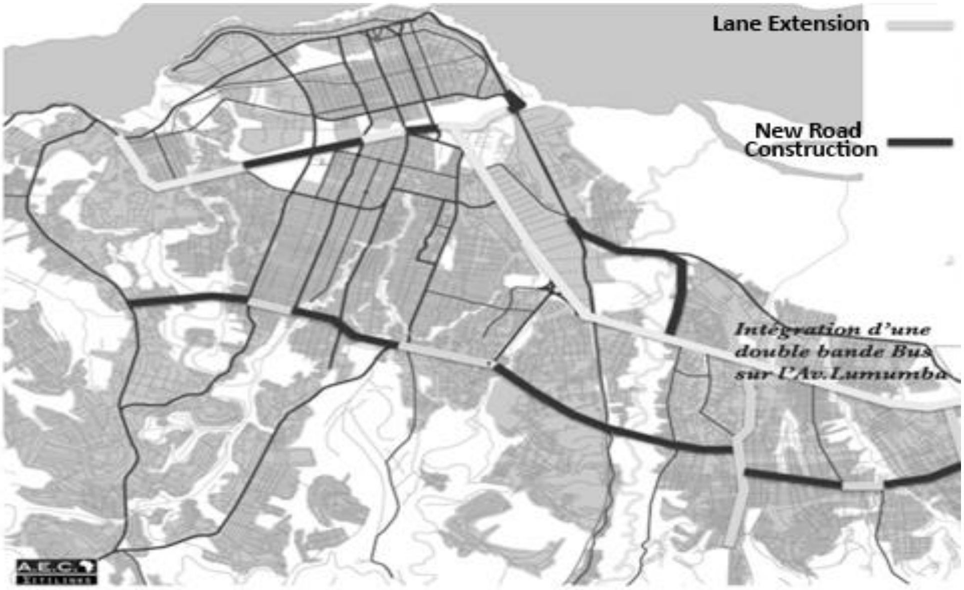
<Figure 6>major road improvement projects (Transurb Technirail, 2011)

Projects 2:

Project 2 is used in the second scenario. It is a set of projects attended to improve connection between East-west and North-South of the city and improve access between quarters.



<Figure 7>North-South improvement projects (Transurb Technirail, 2011)



<Figure 8>East-West improvement projects (Transurb Technirail, 2011)

5.4. Construction of Relevant Transportation Database

As it is the case in most of developing countries, a ready to use transportation database was not available. Therefore, a transportation database of the base year was constructed from scratch based on data and information collected from the government agencies and other organizations. The database includes the transportation network, land-use and socio-economic information. This section describes steps taken in building the transportation database for the base year 2015.

Socio-economic Database:

The Travel Demand Forecasting requires socioeconomic data as inputs to the model. These socioeconomic data include the population and employment data. This section briefly explains steps taken in the estimation of population and employment of Kinshasa City.

In the planning process, socioeconomic and land-use data are compiled and coded to TAZs units to give the transportation planner an understanding of the way land is used in each section of the planning area. The census unit or TAZs (Transportation Analysis Zones) used in this case study of Kinshasa was the smallest administrative unit which is the Quarter (Quartier in French). Therefore, the population and Employments data had to be estimated at the quarter level based on available data and information.

Population Estimation:

The 2015 population of Kinshasa was estimated to be about

11.5 million inhabitants. The city is the largest in the country and is considered by the United Nations as a demographic growth rates among the highest in the world, around 4.2%. By 2025, it must be prepared to manage a population of approximately 17 million people with densities of approximately 800 inhabitants per hectare in areas around the CBD Gombe and the eastern of N'Djili municipality (Transurb Technirail, 2011).

In the present study, the estimation of the population is based on recent estimates and projections of the Nation Institute of Statistics (INS) and the local government or Hotel de Ville, which allowed assessing the current proportions of the population and its spatial distribution within the agglomeration.

The main challenge is to estimate the population at the quarter level for the base year since the National Institute of Statistics only forecasts the total population of the whole city and rarely at the quarter level. Fortunately, in some of studies such as the household survey "enquête 1-2-3" conducted by the National Institute of Statistics (INS, 2012), the estimation of population at the quarter level could be found. Other sources of the population estimations at quarter level include the service of population of the Hotel de Ville, historical and recent official publications (Bienvenu Bolia Ikoli, 2014) (Plan, 2005)

These different data are used to determine the proportions or distribution of the population of each quarter over the total population of the city. These proportions are then used as weighted factors for estimating the base year and future population under the assumption that the proportions of the population remain the same or fixed. Using this method, the population of each quarter is estimated as follows:

$$P_i = w_i \times T_p \qquad \text{(Equation 5.2.1)}$$

Where, P_i is the population of quarter or zone i, w_i is the weighted factor of quarter or zone i and T_p is the target year's total population of the City.

The total population of the base year 2015 is estimated to about 11575000 inhabitants, according to the National Institute of Statistics. Using this information and the Equation 5.2.1, the population of each quarter is estimated on a spreadsheet computer program.

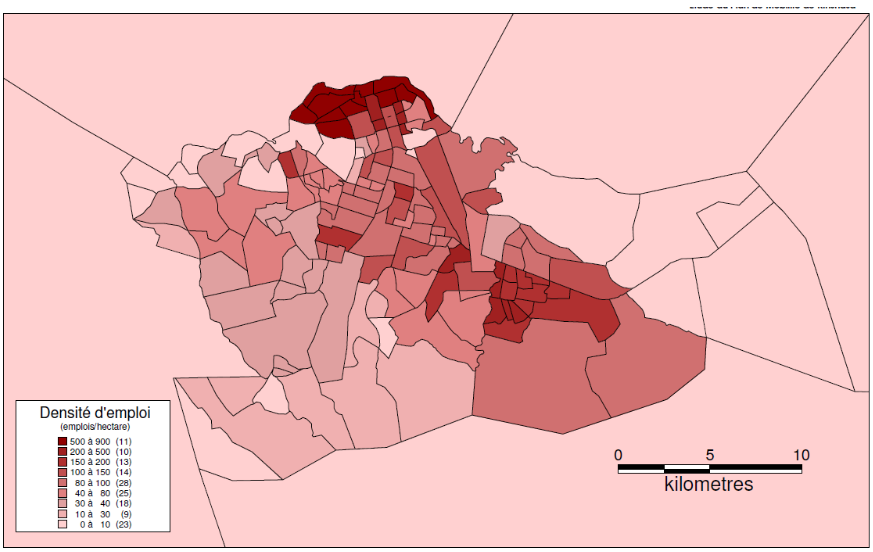
<Table 6>Population of Kinshasa (INS, 2014)

Years	Population
2009	8398000
2010	8683000
2011	9629000
2012	10083000
2013	10558000
2014	11055000
2015	***11575000***

Employments Estimation

A map of 2011 employments density of Kinshasa was produced after a study conducted the same year (Transurb Technirail, 2011). In this study, data from the survey report "2005 INS 1-2-3" was used to estimate the number of jobs (in full time equivalents) in Kinshasa to over 3.5 million in 2011 for a population of 9 500 000 inhabitants. This estimation included both formal and informal Jobs or employments and was based on percentage of the active population. It was found that, the formal sector jobs are mainly concentrated in the CBD Gombe as illustrated by the density map below. The density of informal activities is very strong in the Kimbasenke neighborhood located in eastern of Ndjili.

In the present study, employments and their spatial distribution are estimated using almost the same methodology as previously in the population estimation and in the 2011 study. Data from the National Institute of Statistics (INS, 2012) are used to estimate the total number of Employments of Kinshasa and the 2011 density map of Kinshasa are used to estimate the proportion or weighted factors of employments at each quarter. These weighted factors are then used to estimate the spatial distribution of employments in terms of number of employments by quarter. In order to estimate the weighted factors from this map, the image map is imported into the GIS software, then matched with the base year vector map using GIS Georeferencing and finally converted to vector.



<Figure 9>Employments Density map of Kinshasa 2011 (Transurb Technirail, 2011)

Network Construction:

This section describes the transportation network database construction, sources of data and gives some detail on ways it was built.

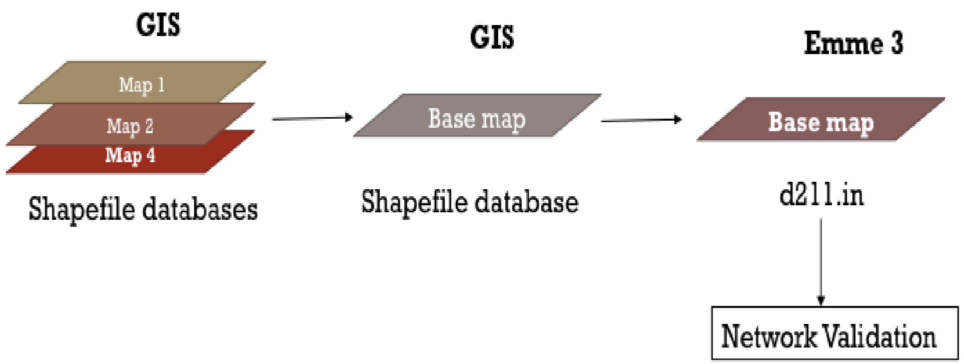
The estimation of travel demand requires an accurate representation of the transportation system serving the region. This is often done by developing an abstract model of the system elements called network for each travel mode. The representation of the automobile system is called a highway network and includes those streets, roads, and freeways that make up the regional highway system.

The network is basically a map of these routes, defined in a manner that can be read, stored, and manipulated by standard transportation planning computer programs. It can also be viewed as an inventory of the existing road system, an official record, for present and future years, of the physical status of the highway system.

Four main steps were taken in building the base year network of the city of Kinshasa.

(1) The gathering of different network information and data from various sources;
(2) Building of a GIS database based on data and information front the previous step;
(3) Conversion of the GIS map into EMME3 input file format;
(4) The network validation.

The GIS database was used for the estimation of accessibility, displaying it level at each zones and road condition on different road sections. The EMME3 database was used for modeling the transportation demand and estimating the travel cost.



<Figure 10>Base Network Building Process

In the first step, different information and data on the road network were gathered from various sources for the construction of the base year network database. These information and data included official inventory of the road network condition and their characteristics from various project reports, official and third-party GIS database of the network and satellite image map services such as Google map, Bing map and Openstreet map.

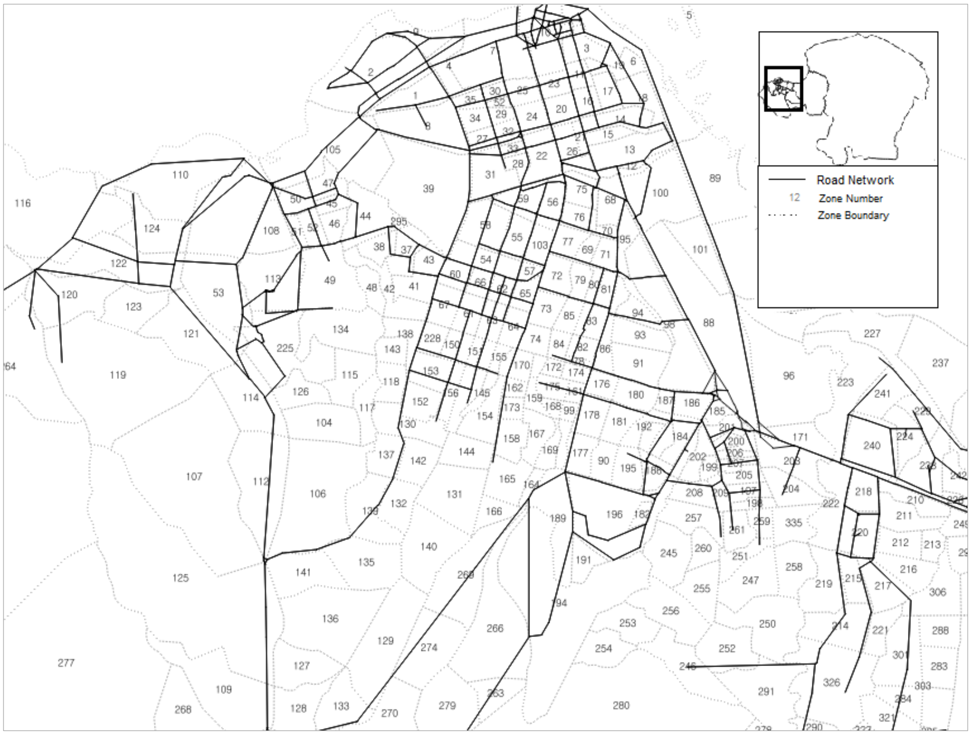
The second step involved the building of a GIS database for the base year, based on data and information gathered from the previous step. The purpose of this step was to construct an optimized network that best represents the base year road inventory. The method consisted of overlapping and comparing different networks and their attributes in the GIS software, then creating one optimal network which would be used as the base network. Some important Network attributes that was gathered from these sources and included into the base network database are listed in the following table:

<Table 7> GIS Network attributes

Name	Description or value
ID	Unique Identifier
Type	Primary, Secondary, Tertiary, streets
Name	Street Name
Tunnel	Yes or No
Bridge	Yes or No
Direction	One-way foreword, reverse, two ways
Access	Private, Public,
Class	Highway, Railway
Number of lanes	Number of lanes by road
Distance	Real distance of road sections
Speed	Design speed and observed speed
Geo Coordinate	x , y coordinates

The software QGIS was used to perform various actions such as displaying maps in layers, filtering data, comparing different maps, polygon to polyline conversion, performing transformations such as Geo-referencing, link' s real distance estimation, creating the base network shapefile database including links, nodes and centroids with their attributes. The figure # show how the built network matches with the satellite road map from Bing with a high accuracy.

<Figure 11>Base Network of City of Kinshasa overlapped with Bing Map

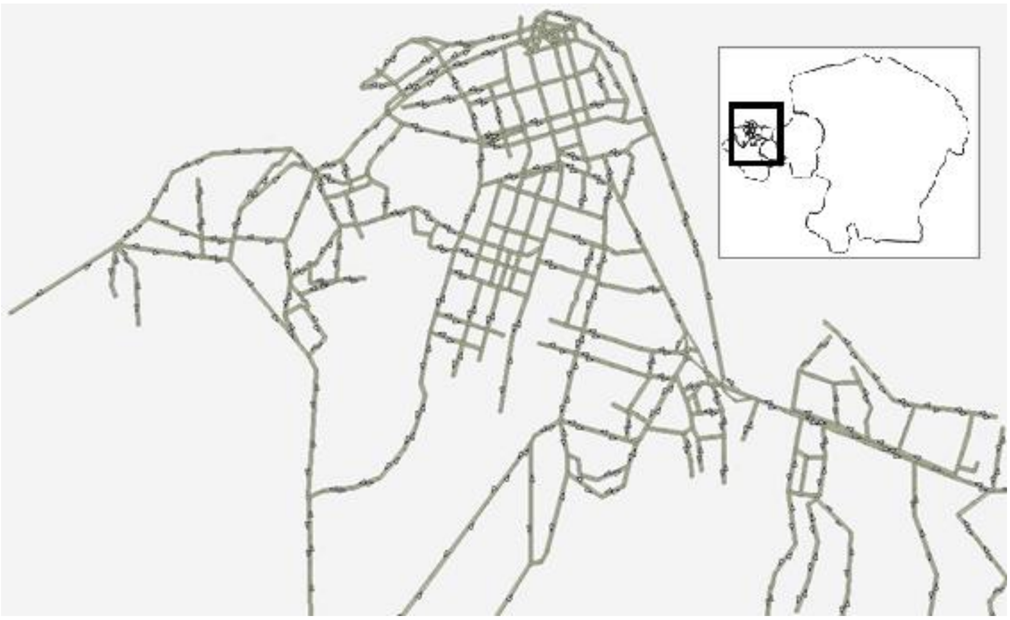


<Figure 12>Developed Road Network of Kinshasa 2015, Shapefile.

The third step involved the conversion of the network into a format that could be used by the transportation demand forecasting software "EMME 3". The Emme 3 tool "Shape file to Emme Conversion" was used to convert the base network shape file to the "d211.in" input file using the link, node and centroid shape databases from the base network shape file. The basic network attributes used in EMME3 database are shown in the following table:

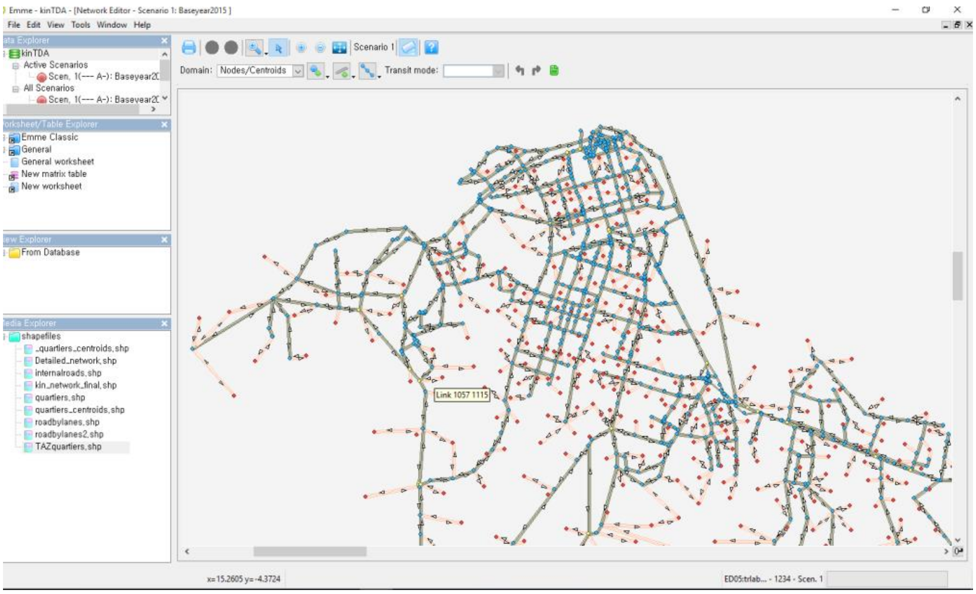
<Table 8>EMM3 Network Attributes

Attributes	Data Type	Constant value
Direction	Integer	- Reverse 1way : -1 - 2 ways : 0 - Forward 1way : 1
Length	Real	in kilometer
Modes	String	User defined
Type	Integer	User defined link type identifier
Lanes	Real	
Vdf	Integer	User defined VDF identifier



<Figure 13>Road Network of Kinshasa 2015, EMME3 input file.

The Last step involved the validation of the base network in the modeling software to check for potential network coding issues. To do this, the Network Validation worksheet was used to identify unused nodes and centroids, that is, nodes and centroids that are not connected; dead end nodes, links for which the values of certain attributes are not the same in both directions, links with lengths that are either shorter or more than 50% longer than the Euclidean distance, links with missing attributes.



<Figure 14> Road Network of Kinshasa, 2015, EMME3 Screenshot

5.5. Analysis and Results

5.1.1. Four Steps Travel Demand Modeling

Study Area and Traffic Analysis Zones

Common modeling practices require a representation of zones as geographic areas dividing the planning region into relatively similar areas of land use and land activity. Zones represent the origins and destinations of travel activity within the region.

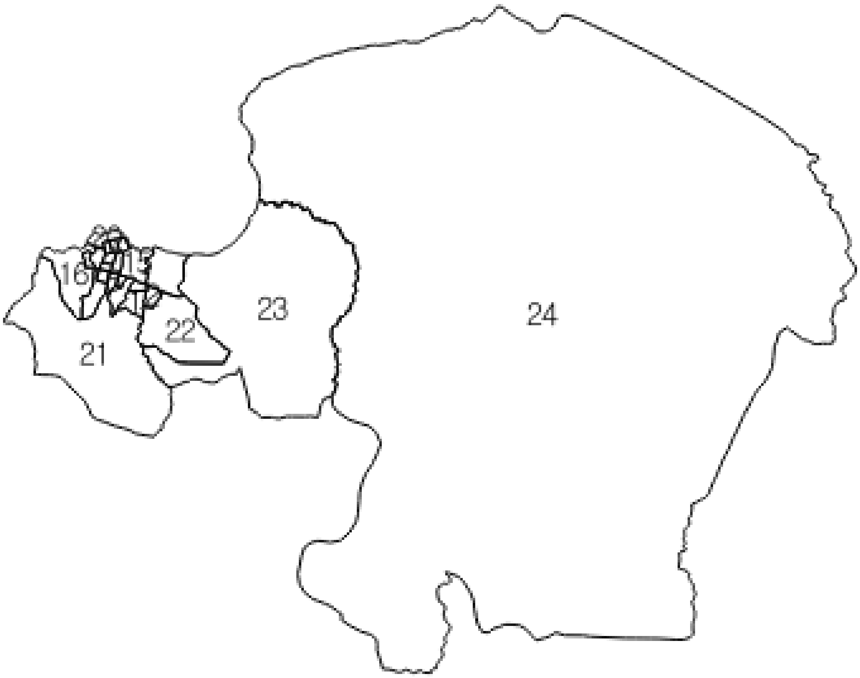
As it is not computationally feasible to represent every household, place of employment, shopping center, and other activity as a separate origin and destination, these entities are first aggregated into zones and then further simplified into a single node called a centroid.

Zones and centroids are then coded and represented in a vector map format to facilitate the analysis.

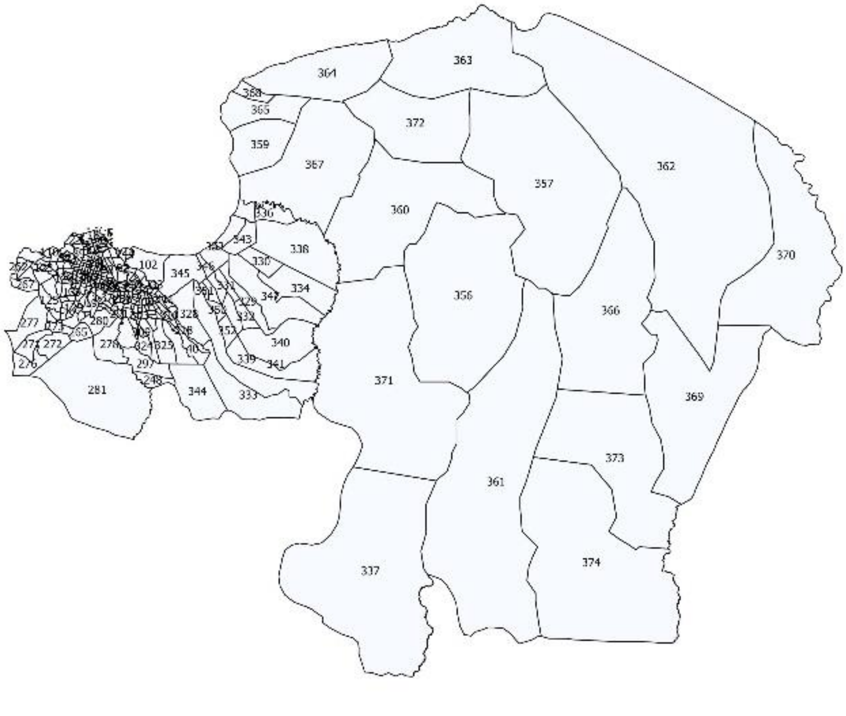
In this study, the smallest administrative divisions, which are the quartiers, are chosen as Transportation Analysis Zones so that zoning systems could follow available census data boundaries, and data estimated in the census survey could be used with minimal manipulation.

However, the available vector map was limited to 24 zones representing the 24 municipalities of Kinshasa city. The only available data for quarters was scanned image maps of each quarter (Bienvenu Bolia Ikoli, 2014). Therefore, the GIS software is used to build a vector map of all quarters using the existing vector map of 24 zones and image maps of the quarters. This is done using the GIS geo-referencing method.

The resulting vector map is shown on the following figures:



<Figure 15>Kinshasa 24 Zones vector map



<Figure 16> Georeferenced TAZs map of 375 Zones of Kinshasa

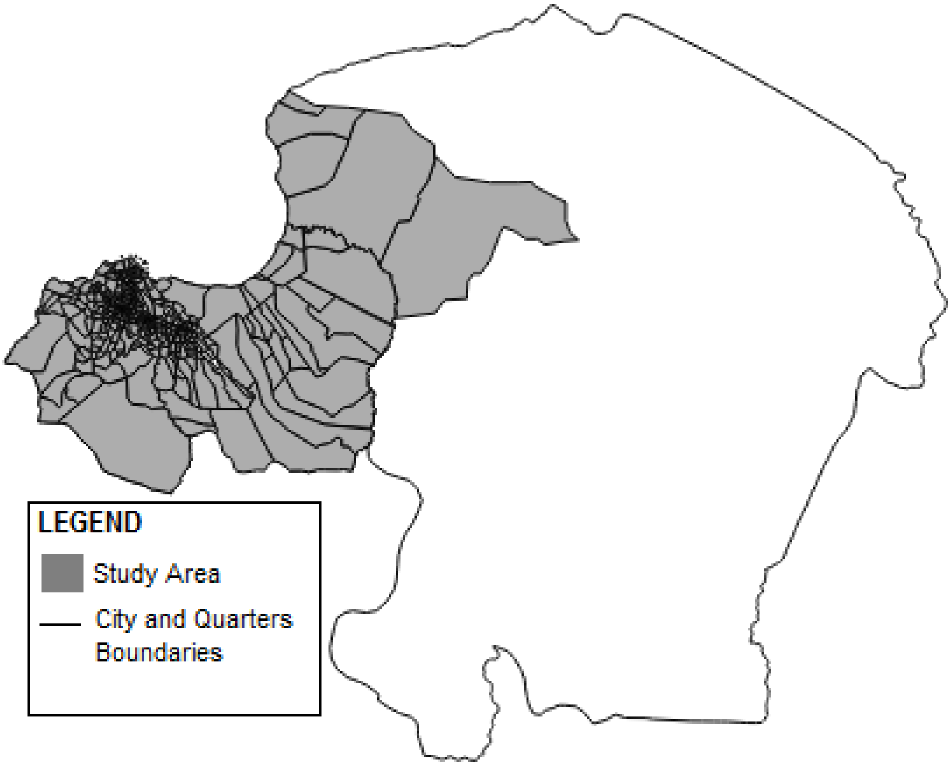
Using the "Polygon centroid tool" available in the Qgis software, zone centroids are placed in the center of activity of the zone. The polygon (zone) centroid is considered as the center of activity in zones with high density of activity, while for zones with low density, an adaptation is made based on satellite image map and local knowledge so that it matches with the center of activity of the zone.

Throughout this study, the 24 municipality zones were considered as super zones or zone groups, containing each of them a certain number of quarters matching with the administrative division structure.

The criteria for zone numbering are based on the habitat types and concentration of the activity at the super zones level and in their alphabetical order at the quarter level, starting from the CBD. For instance, quarters located in the CBD super zone which is the municipality of Gombe are given numbers starting from one in their alphabetical order. Those located at the most Eastern municipalities are given the last numbers since they have lower quality of habitat and lower density or number of activities. This numbering system is adopted mainly for facilitating the interpretation of the results of this study.

Finally, another issue is the selection of zones to be analyzed. Kinshasa viewed as a whole is a mix of urban, peri-urban and rural areas. It covers an area of 9,965 km^2 and approximately 600 km^2 only is urbanized (De Saint Moulin, 2005). Thus, in this study only area identified as urban or some peri-urban is considered based on previous studies, projects, the availability of road network and local knowledge. A total of 350 zones was selected for the analysis.

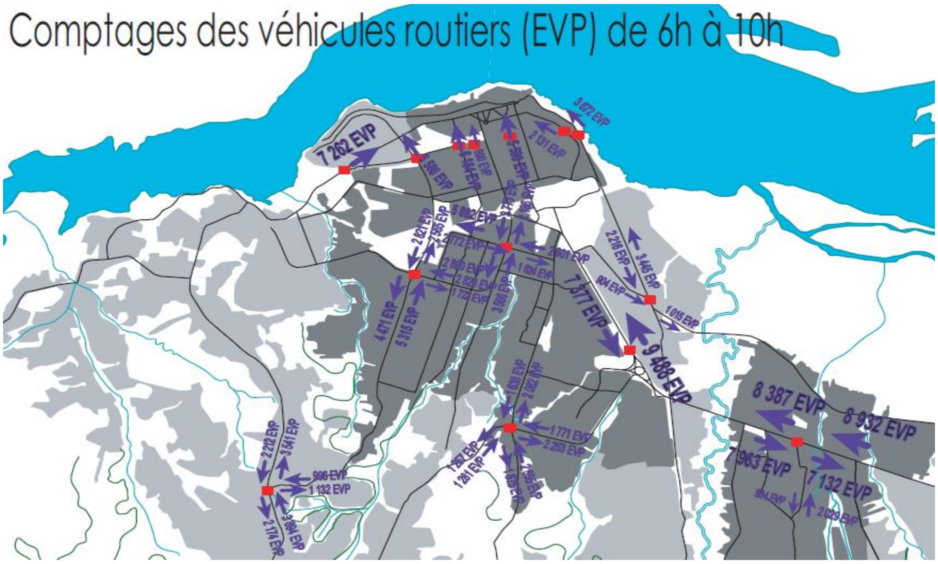
The selected study area is presented on the bellow figure



<Figure 17> Study Area

Input Data:

The traffic count data from 2006 and 2011 studies is used to estimate the average daily traffic and the validation results. Socioeconomic Data described in chapter 3 and 5 are used in this section.



<Figure 18> Kinshasa traffic count survey 2011 (Transurb Technirail, 2011)

Trip Generation Model:

Trip generation is the first stage of the classical first generation aggregate demand models. It aims at predicting the total number of trips generated and attracted to each zone of the study area. This stage answers the questions such as "how many trips originate at each zone", given some proprieties of the zones such as population, employment, number of cars, income, etc.

This section briefly explains the process used in this step.

The estimation of trip productions using disaggregate travel demand models typically uses a cross-classification of household size data with a measure of wealth, such as income or the number of automobiles available to the household. For this case study, however, no cross-tabulations were yet available for the city of Kinshasa. As a result, the forecasted trip production rates from the 1991 household survey are used to calculate the total trip productions using the average values for each zone respectively. These trip rates are expressed in daily trip rate by person. Using these values, the trip for each zone is estimated on a computer spreadsheet as follows:

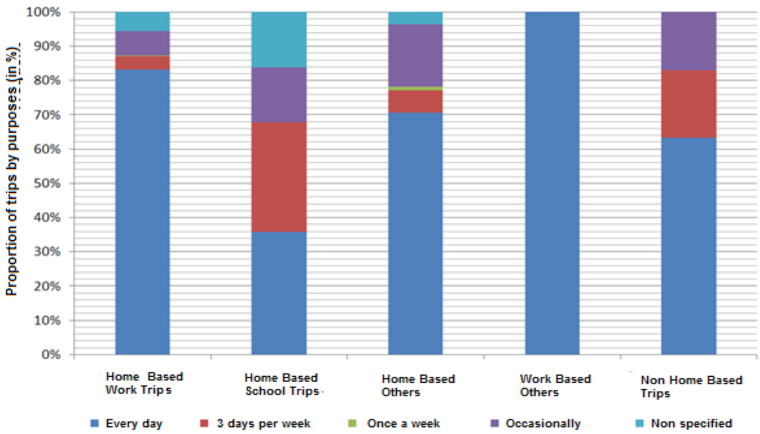
Zonal trip production = Zonal trip rate * Zonal population

Trip attractions are also calculated on a computer spreadsheet using the following expression:

Zonal Trip Attraction = zonal trip rate * number of employments

The input data for these calculations include both formal and informal employments estimated from the percentage of active population.

In order to efficiently estimate the accessibility to jobs, the Home-Base Work Trips should be separated from other trips, thus, trip purposes are split into Home-Based Work Trips and Home-based Other & Non Home Based Trips based on trip purpose proportions presented in the household survey report and recent studies (Transurb Technirail, 2011)



<Figure 19>2011 trips frequency by purpose (Transurb Technirail, 2011)

The final step in the trip generation phase is the balancing of regional trip productions and attractions. The trip distribution phase of the travel demand forecasting process requires that the total number of regional trip productions equals the total number of regional trip attractions for each of the trip purposes. This condition can be met by applying a balancing factor to the attraction trips for all TAZs. Since there the external trips are not considered in this analysis, the balancing factor is calculated simply by dividing the total trip generations by trip attractions.

At this point, values for the productions and attractions are ready to be used in the trip distribution phase of model development in order to prepare the person-trip tables. Therefore, the production and attraction data are imported into the EMME3 software and saved in form of origin and destination matrices for each trip purposes respectively.

Trip Distribution Model

Trip distribution is the second stage of travel demand modeling. In this stage, the generated trips from the previous stage are distributed to all other zones based on the choice of destinations. There are a number of methods to distribute trips among destinations; in this study, the entropy-maximizing model was used.

The entropy-maximizing is a particular case of the general gravity model. It starts with a function of travel costs (deterrence function) which is a negative exponential function of travel cost and is given by the following expression:

$$T_{ij} = \alpha O_i D_j \, e^{-\beta c_{ij}} \qquad \text{equation 5.5.1}$$

Where O_i and D_i are origin and destination matrices respectively, c is the travel cost, α and β are parameters to be calibrated. i and j represent the origin and destination zones respectively.

At this stage, the trip pattern in the study area is represented by means of a two dimensional production-attraction (P/A) matrix in which cells of each row i contain the trips originating in that zone which have as destinations the zones in the corresponding columns.

The sum of the trips in a row should be equal to the total number of trips emanating from that zone. This following figure illustrates the situation:

Zones	1	2	...	j	...	n	O_i
1	T_{11}	T_{12}	...	T_{1j}	...	T_{1n}	O_1
2	T_{21}	T_{22}	...	T_{2j}	...	T_{2n}	O_2
$\vdots$	...	...	...	...	...	...	$\vdots$
	T_{i1}	T_{i2}	...	T_{ij}	...	T_{in}	O_i
$\vdots$	...	...	...	...	...	...	$\vdots$
n	T_{ni}	T_{n2}	...	T_{nj}	...	T_{nn}	O_n
D_j	D_1	D_2	...	D_j	...	D_n	T

<Figure 20> Representation of Origin destination matrix

Where, $D_j = \sum_i T_{ij}$, $O_j = \sum_j T_{ij}$, and $T = \sum_i T_{ij}$

With T_{ij} the number of trips between origin i and destination j. Oi is the total number of trips between originating in zone i and Dj is the total number of trips attracted to zone j.

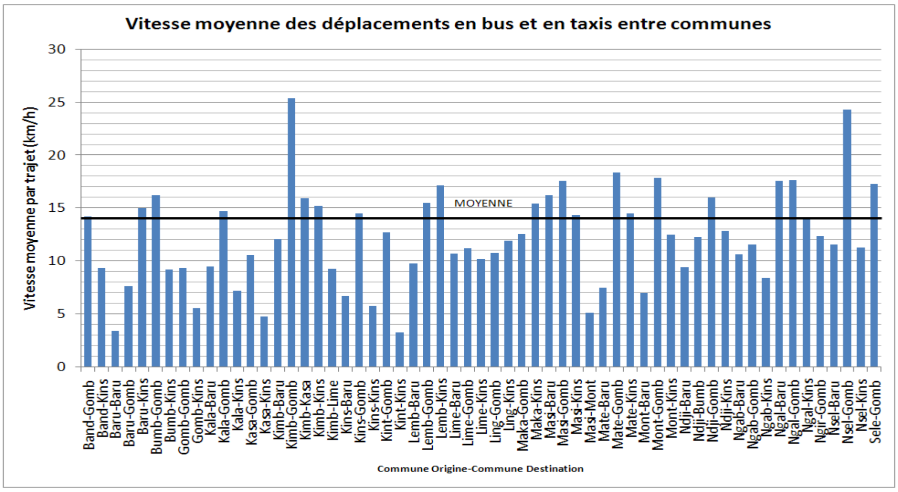
The O-D matrix is estimated using the two dimensional balancing procedure in the EMME3 software which takes as inputs the travel time or generalized cost matrix, the beta value (coefficient of friction) and a constraint matrix of observed or surveyed travel pattern.

The skim matrix of travel time was first calculated through the assignment of a trip table based on free-flow speeds on the highway network. However, during the assignment procedure, any trip which begins and ends at the same zone (the intra zonal demand) is not actually assigned onto the network, so there is no corresponding travel time computed for these O-D pairs. Thus, the intra zonal travel time matrix associated with each zone (in an origin matrix) was estimated using the nearest-neighbor algorithm. This algorithm consists of identifying the zones adjacent to each of the all internal zones, taking the free-flow travel time from the zone of interest to all adjacent zones, calculating a mean for that set of times, and halving that value to arrive at the assumed intra zonal travel time.

The coefficient of friction Beta is intended to capture the behavioral components of the desire to travel (the higher the value of Beta, the higher the cost associated with travel). The value of Beta is typically calibrated via an iterative procedure, so that the resulting O-D matrix has the property that it matches the mean travel time of the observed matrix (usually obtained from a survey).

In this study, however, data available for the calibration of Beta parameter were not enough. Therefore, two options were tested in order to obtain an acceptable result. The first option was to reconstitute the observed travel pattern of the 2011 survey (Transurb Technirail, 2011) by building a matrix that could serve as a constraint matrix in the calibration and by estimating the observed average travel time using the observed average travel speed. The second option was to borrow parameters from other cities or countries, assuming that travelers of both countries have similar behavior, especially in the perception of the travel cost.

However, this method presents an issue regarding the transferability of parameters. Therefore, criteria for selecting the country were based on the proximity, similarity of administrative function, culture and the availability of a recent travel behavior study. The city of Dares-Es-Salaam was selected and parameters from the study on travel behavior conducted by JAICA (JAICA, 2007) were used. After testing the results, first option was less convincing, therefore, second option was chosen for this analysis.



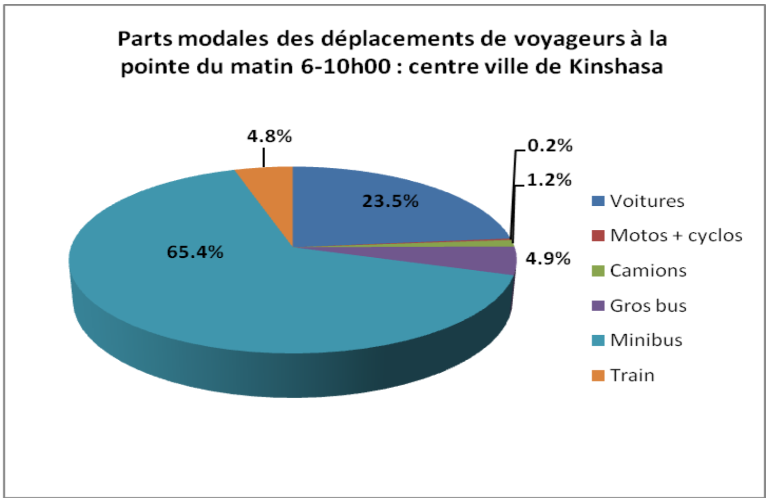
<Figure 21>2011 Observed Average Speed O-D between super zones (Transurb Technirail, 2011)

In order to account for congested conditions, data from 2011 survey are used to produce a matrix of congested travel times, which were used to perform the trip distribution model.

Mode Choice Analysis

The third stage in travel demand modeling is the modal split or mode choice. In this stage the trip matrix obtained from the trip distribution is divided into number of matrices representing each mode.

<Figure 22> shows the modes share in Kinshasa during morning peak from 6 to 10am, based on a survey conducted in 2011 (Transurb Technirail, 2011). According to this survey, more than 80 percent of motorized trips are made using para transits or informal transports which use small buses and cars in their majority. The purpose of our model being to create a level of congestion that best reflect the reality so that it can be used in the accessibility analysis, in this study, only the auto mode was analyzed. All person trips are converted into vehicle trips using the vehicle occupancy and passenger car equivalent factors.



<Figure 23>Modal Shares at morning peak, 2011 (Transurb Technirail, 2011)

Time-Of-Day Characteristics:

This is the point during the travel-demand modeling process at which the daily trip tables, which had been maintained in production-attraction format (P-A) are converted to origin-destination format (O-D) for the time periods to be analyzed.

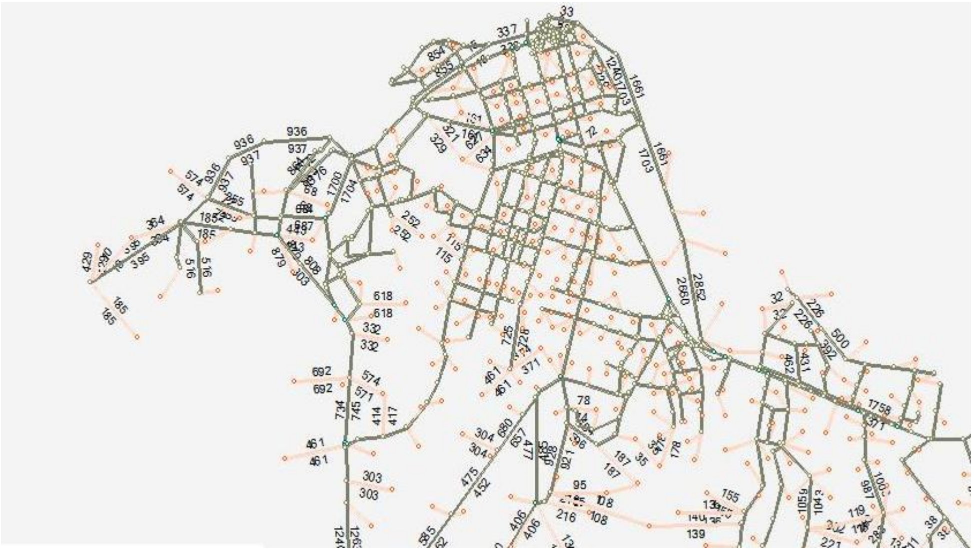
Assigning traffic by time-of-day considers the relative levels of congestion and the alternate optimal travel paths between zone pairs that vary by time period. The time period for this study is the AM peak. Thus, directional trip ratio from 1991 survey is used.

Traffic Assignment:

The last stage of Travel Demand Analysis is the Traffic assignment which consists of allocating trip tables to the specified transportation system with the aim of reproducing the pattern of vehicular movements which would be observed when the travel demand represented by the trip matrices to be assigned is satisfied.

The traffic assignment is performed using the Standard Traffic Assignment module of EMME 3 which a standard user-optimal equilibrium traffic assignment using linear approximation of Frank and Wolfe.

The outputs are sets of speeds and volumes on network links, and travel time matrices of 350x350 size. This process is repeated for all scenarios. The scenarios are all applied to the base year which is 2015. Their outputs are used as inputs for the estimation of the accessibility.



<Figure 24>Base Year Traffic Assignment Results

<Figure 25> Traffic Assignment Results, Scenario 2

5.6. Accessibility Estimation

Results of traffic assignment from the travel demand forecasting are used for estimating the accessibility to work of each zone. This is done using the QGIS software which also includes the transportation database built previously. The aim is to simulate and visualize both changes on road conditions and accessibility at each zones of the study area by scenario.

The methodology for estimating the accessibility as well as performance measures developed in this study are described in more detailed in chapter 4.

The accessibility is measured here using the gravity-based accessibility calculated as following:

$$A_i = \sum_{j=1}^{n} W_j \, e^{-\beta c_{ij}} \qquad \text{(Equation 1)}$$

where, A_i is the accessibility of zone i, W_j the activity or opportunity to reach in zone j, c_{ij} is the travel cost of reaching zone j from zone i, β the travel impedance parameter and n is the number of zones or quarters.

Chapter 6. Research Results

This section presents results of the case study of Kinshasa by scenario. There are 4 scenarios in total named as Scenario 0, 1, 2 and 3.

The Scenario 0 is the reference scenario in which the base year is analyzed under prevailing conditions.

In scenario 1, project 1 (which is a s set of projects) is applied to the base year in order to evaluate its impacts on mobility and accessibility. This set of projects are described in details in chapter 5, section 5.3.

In the scenario 2, the set of projects 2 is applied to the base year, without considering scenario 1. More details on this set of projects is given in chapter 5, section 5.3.

Finally, in scenario 3, both scenario 1 scenarios 2 are applied to reference scenario to see how they perform in solving the problem faced by the city of Kinshasa.

For each scenario, results are presented in forms of table, chart and map.

Results presented on the table are aggregated accessibility index results of the total area for the corresponding scenario. They include the accessibility indexes of the whole study area, the zone with the lowest accessibility index and the zone with the highest accessibility index, with their corresponding average travel time and zone' s identifier. It also shows the gap accessibility.

The chart shows results of all 350 zones in the ascending order, starting from zone 1 to 350. The main purpose of was to show the distribution of accessibility over all zones.

A numbering system was adopted mainly for facilitating the interpretation of the results of this study (Chapter 6).

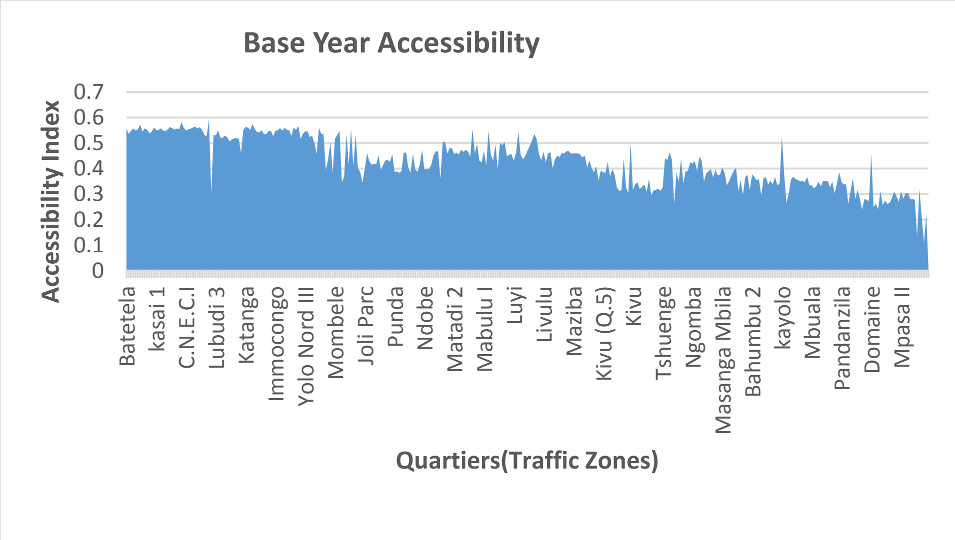
The map displays results of the simulation generated by the tool we have built in QGIS. The map includes a legend that describes symbols and colors used to display both road conditions and accessibility results. The unit of LOS of road links is the speed in Km/h. they are categorized in 3 groups (1 to 14 km/h, 15 to 28 km/h and 28 to 60 km/h). The unit of accessibility is the accessibility index (AI) of the zone developed in his study. They are also divided in several color categories. The darker is a zone the more accessible it is.

Results of scenarios are as follows:

6.1. Scenario 0: Accessibility of the Base Year

<Table 9> Scenario 0: Base Year Accessibility Index Table

Unit	Accessibility Index	Average i-j travel Time	Zone
Maximum Unit	1		All TAZs
Average Accessibility	0.36	89.23 Min	All TAZs
Minimum Accessibility	0.07	200.29 min	349 (Menkao)
Maximum Accessibility	0.53	73.88 Min	37 (Camp Kokolo)
Gap (min- Max)	-0.46		



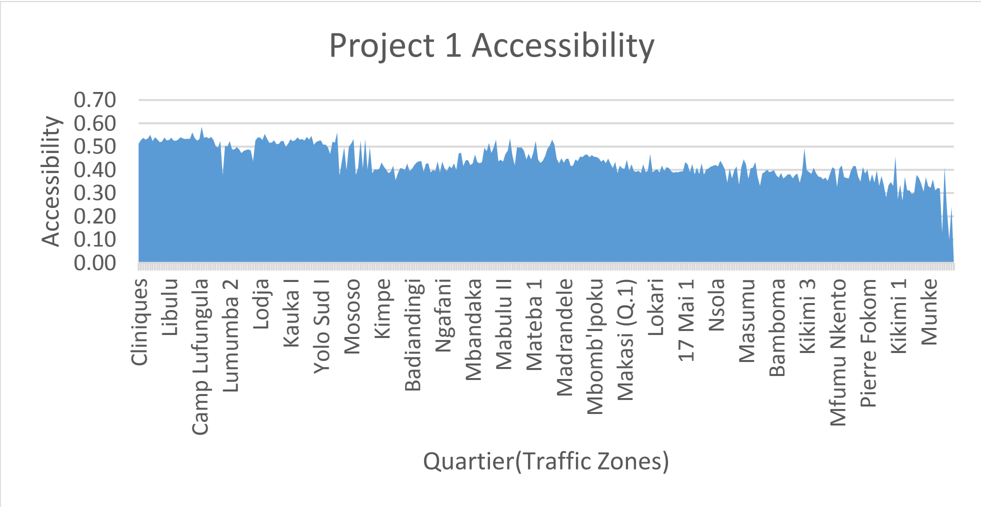
<Figure 26> Base Year Accessibility Distribution by Quarters (TAZs)

<Figure 27>Base year Map of Accessibility and Road conditions

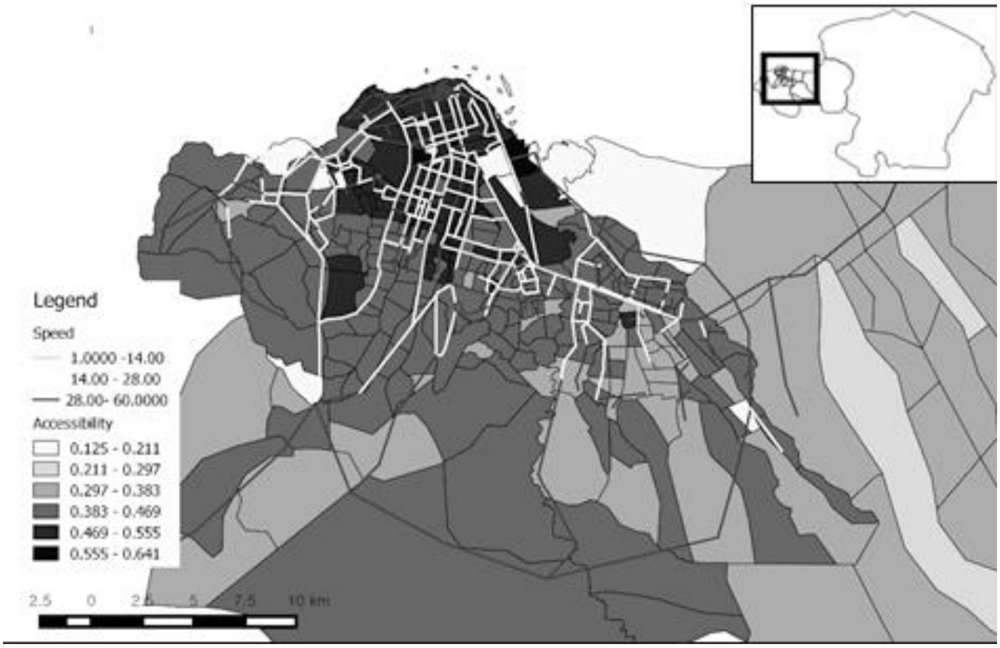
6.2. Scenario 1: Accessibility after Introducing Project 1:

<Table 10> Scenario 1: Accessibility Index Table

Unit	Accessibility Index	Average i-j Travel Time	Zone
Maximum Unit	1		All TAZs
Average Accessibility	0.59	64.30 Min	All TAZs
Minimum Accessibility Index	0.10	99.7 Min	349 (Menkao)
Maximum Accessibility Index	0. 52	73.88 Min	29 (La voix du peuple)
Gap (min- Max)	-0.49		



<Figure 28>Accessibility Distribution after the Implementation of Project 1

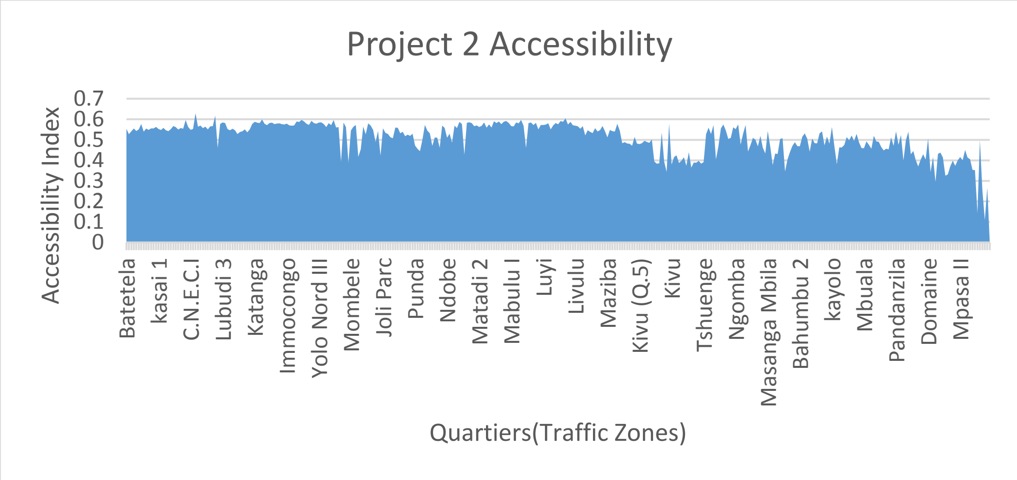


<Figure 29>Scenario1: Map of Accessibility and Road condition

6.3. Scenario 2: Accessibility after Introducing Project 2

<Table 11>Scenario 2: Accessibility Index Table

Unit	Accessibility Index	Average i-j Travel Time	Zone
Maximum Unit	1		All TAZs
Average Accessibility	0.51	48 Min	All TAZs
Minimum Accessibility Index	0.11	148 Min	349 (Menkao)
Maximum Accessibility Index	0.62	49 Min	37 (Camp Kokolo)
Gap (min- Max)	-0.51		



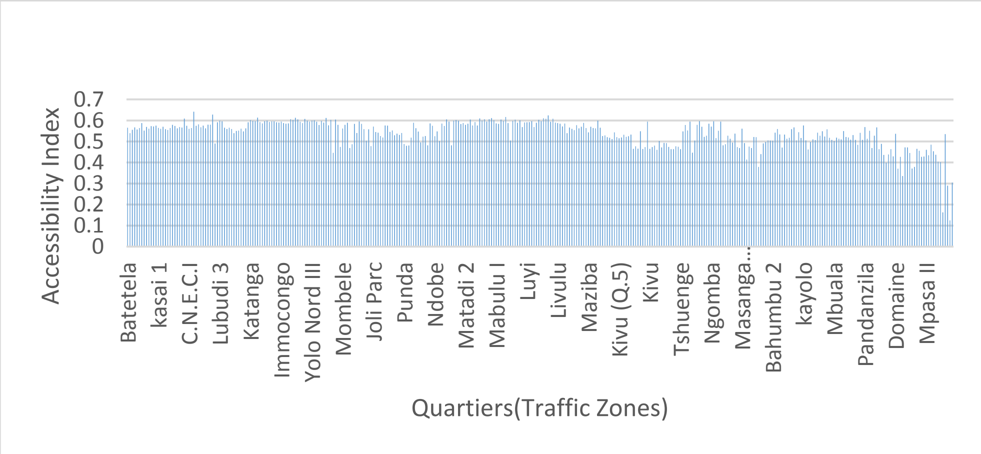
<Figure 30> Accessibility Distribution after the Implementation of Project 2

<Figure 31>Scenario 2: Map of Accessibility and Road Condition

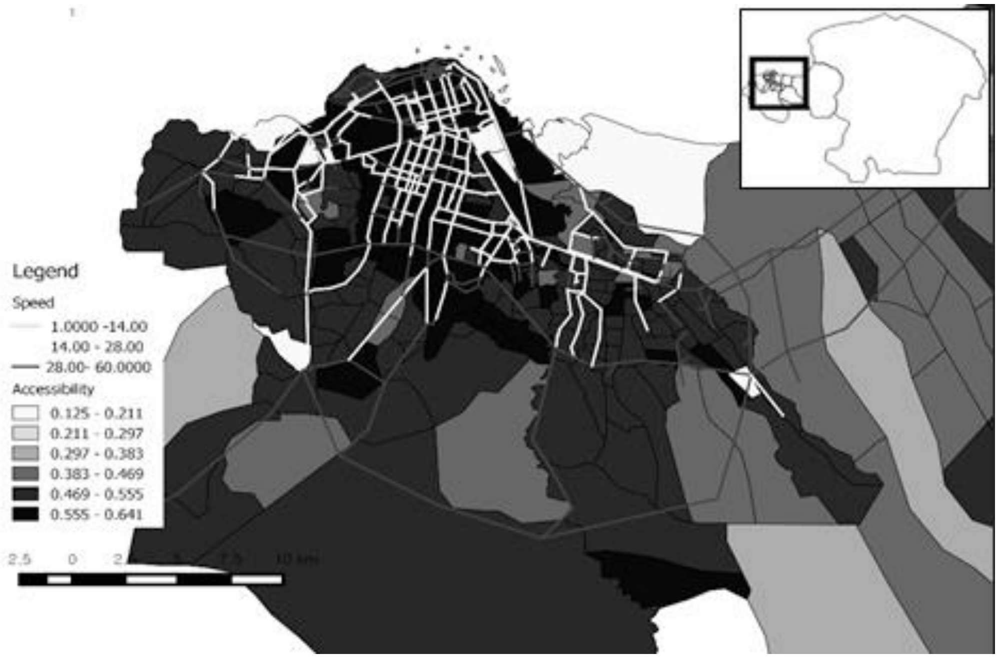
6.4. Scenario 3: Accessibility after the Implementation of Both Projects

<Table 12>Scenario 3: Accessibility Index Table

Unit	Accessibility Index	Average i-j Travel Time	Zone
Maximum Unit	1		All TAZs
Average Accessibility	0.54	43 Min	All TAZs
Minimum Accessibility Index	0.12	140 Min	349 (Menkao)
Maximum Accessibility Index	0.62	44 Min	29 (La voix du peuple)
Gap (min- Max)	-0.50		



<Figure 32> Accessibility Distribution after the Implementation of Project 2



<Figure 33> Map of Accessibility after the Implementation of Project1 and 2

<Table 13>Summary of Accessibility Results

Scenarios Number	Description	Accessibility Index	Average Travel Cost	Accessibility Gap
Scenario 0	Base year Congested Travel Time	0.36	89 Min	−0.47
Scenario 1	Project 1 : Road Improvement Plan	0.43	64 Min	−0.49
Scenario 2	Project 2: Road Improvement Plan	0.51	48 Min	−0.51
Scenario 3	Project 1 and 2	0.54	43. Min	−0.52

Chapter 7. Discussion

This chapter discusses on the consistency of results found in this research with the reality, previous researches.

Results show that, in terms of mobility, scenario 1 performs better than scenario 2 especially on the major Eastern part road named Boulevard Lumumba, with a significant increase in speed compared to the base year. This major road is one of the busiest road (Transurb Technirail, 2011) since it is the only road that connects Eastern to western and Northern part of Kinshasa. The construction of another road parallel to the existing one was proposed as a short term solution to urgent problems including traffic congestion on that road. Therefore, in this aspect, scenario 1 has reached his goal.

With regard to the accessibility, results show that scenario 2 performed better for the whole results. One of the objectives of this set of projects is to improve accessibility between quarters (Transurb Technirail, 2011) by improving the connections between East-West and North-South as well as the conditions of some selected roads. The main purpose was to improve the road network in order to facilitate the integration of public transportation systems such as BRT, which will efficiently serve quarter zones between East-West and North-South. Results of this research confirm this evidence. Another factor that has contributed in increasing accessibility in the scenario 2 is probably the use of two strategies of improving accessibility which are the mobility and transportation network connectivity (by connecting East-West and North-South) (Litman, Evaluating Accessibility for Transportation Planning, 2011).

However, accessibility of the less accessible zone has slightly increased from 0.07 to 0.10, 0.11 and 12 for scenarios 0,1,2,3 respectively. This result shows how expensive (in terms of travel cost) it would be to improve accessibility of this zone. If we consider our initial objective which was to identify the project that best increase the accessibility, we may say that both projects provide almost the same performance. Therefore, the increase in the total average accessibility for scenario 2 came mainly from the increase in the maximum accessibility.

Results also indicate that zones located near the CBD including northern and Western zones, are more accessible to jobs than those located in the Eastern and Southern of the city for all scenarios. This is in part due to the land use pattern of Kinshasa which is considered as mono-centric in terms of location of employments where the majority of jobs including formal and informal jobs are concentrated in the center of urban area near the CBD (see Figure 34). Zones located near this mono-centric activity area have better access to jobs. They also have better infrastructure than Eastern and Southern zones. Therefore, these results are also consistent with the theory of gravity based accessibility which states that the number of activities reachable by a zone depends on the nearby number of activities and the travel cost.

Another aspect to consider is the type of employments or jobs used in this analysis. If we consider only formal employments, this result would probably be considered unrealistic since the number of formal employments is less than the informal (INS, enquete 1-2-3, 2012). Majority of them are concentrated at the mono-centric activity area. Thus, results of accessibility would be very low or even zero for the majority of zones. Therefore, this aspect should be considered when it comes to interpret these results.

Among accessibility measures developed in this study, the accessibility gap is found to be one of the most important measures. Results show that the more the accessibility gap between the most accessible zone and less accessible zone deceases, the more the accessibility of the overall study area increases. This means that at the equilibrium state, the accessibility gap is 0.

Another fact is the relationship between the accessibility gap and the average accessibility of the study area. Results show that the accessibility of the less accessible zones gets better when the absolute value of the accessibility gap is getting less than the average accessibility of the whole study area. Thus, the accessibility gap is a useful measure while planning for a balanced accessibly.

Chapter 8. Conclusion

Throughout this study, accessibility performance measures were developed using the gravity-based accessibility model. These measures were applied to a practical case of the city of Kinshasa in order to show its usefulness and applicability in solving problems and reaching planning goals.

A transportation database for Kinshasa was built using data collected from government agencies and various other sources. GIS and EMME3 were used for modeling the accessibility to jobs by scenario of proposed major road infrastructure improvement projects. Finally, the developed accessibility indexes were used to identify scenarios that best increase the accessibility.

Results show that, the accessibility gap is one of the most important measures to consider while planning for a balanced accessibility.

In the case of Kinshasa, Eastern and Southern zones are found to be less accessible than Western and Northern zones for all scenarios. This result is consistent with the reality and the gravity based accessibility theory in that, since Eastern and Southern zones are located far from the center of activities, their access to jobs is reduced. Accessibility of these zones has increased after introducing the two selected sets of projects.

In terms of mobility, results show that scenario 1 performed better than scenario 2 especially on the major Eastern part while with regard to the accessibility scenario 2 performed better. This result also was consistent with the purpose of both projects. However, the accessibility gap between the more and less accessible zones is still very high. Also, the speed on road sections remained slow in the majority of roads and slightly increased in the Eastern roads.

For this case study of Kinshasa, it is therefore recommended to prioritize solutions that will effectively decrease the accessibility gap and increase the mobility. For instance, the decentralization of activities by planning more accessible land use patterns to reduce travel distances, and favor mobility solutions by improving roadways, rideshare and public transit service. The solution on the decentralization of activities was not tested in this research due to the lack of data on future urban planning projects. Thus, further researches are needed to test this solution.

Although the results were consistent, the limitation of this research remains mainly on the accuracy of data used for the travel demand forecasting; the use of travel time instead of generalized cost and use of auto mode only. Further research is also needed to consider other options such as public transportation modes.

References

Administration, N. R. (1998). *.Evaluating People ' s to Reach Desired Goods, Services and Activities page 2.*

Ahmed El-Geneidy, A. C. (2011). *L'évaluation Des Plans De Transport Grâce Aux Mesures D' accessibilité.*

Banque Mondiale. (Mission d' expertise sur la mobilité urbaine à Kinshasa, rapport technique.). *Juin 2013.* Kinshasa.

BECEOM. (Juin 1994). *Plan directeur de développements du secteur des transports urbains à Kinshasa, rapport final.*

Bienvenu Bolia Ikoli, l. H. (2014). *Kinshasa ma ville, ma capitale. .*

Briassoulis. (2001). *Sustainable development and its indicators: Through a (planner's) glass darkly. Journal of Environmental Planning and Management, 44(3), 409-427.*

Carolin Folkesson, M.-C. M. (n.d.). *Accessibility Measures for Analyses of Land Use and Travelling with Geographical Information Systems.*

Coppola, E. P. (2012). *Gravity-Based Accessibility measures for Integrated Transport-land Use Planning (GraBAM), in Angela Hull, Cecília Silva and Luca Bertolini (Eds.).*

Environment, U. D. (1996). *Policy and Procedure Guidelines, PPG 6.*

Hansen, W. (1959). *How accessibility shape land use. Journal of the American Institute of Planners, 25(2), 73-76.*

Hôtel de ville de Kinshasa. (2016). *Arrêtés portant fixation du tarif des transports en commun des personnes et des itinéraires officiels à parcourir sur toute la ville de Kinshasa.*

Ikoli, B. B. (2014). *Kinshasa ma ville, ma capital.*

INS. (2012). *Enquête 1-2-3.*

JAICA. (Dar-es-Salaam Transport Policy and System

Development, technical report 06 & 07). *Jun 2008.*

Jean Flouriot, l. C.–M.–M. (2005). *Trente ans après la publication de l' Atlas de Kinshasa, .*

Lerman, B.–A. M. (1985). *Discrete Choice Analysis. MIT Press.*

Litman, T. (2003). *Measuring Transportation: Traffic, Mobility and Accessibility.*

Litman, T. (2011). *Evaluating Accessibility for Transportation Planning.*

Matthieu Kayembe Wa Kayembe, M. D. (2005). *Cartographie de la croissance urbaine de Kinshasa (R.D. Congo) entre 1995 et 2005 par télédétection satellitaire à haute résolution. .*

Matthieu Kayembe Wa Kayembe, M. D. (Africa 2009). *Cartographie de la croissance urbaine de Kinshasa (R.D. Congo) entre 1995 et 2005 par télédétection satellitaire à haute résolution.*

Ministère des transports et communications, g. d. (Novembre 2006). *Etude institutionnelle de la sécurité routière et préparation d' un programme d ' action à court terme en république démocratique du Congo, Rappo.*

Ministère des transports et communications, groupe d' études des transports, CIMA International. (2006). *étude de réforme du cadre institutionnel des transports urbains en république démocratique du Congo, Phase II, Rapport final de la mission, Pro.*

Ministère des transports et communications, groupe d' études des transports, CIMA International. (avril 2006,). *étude de réforme du cadre institutionnel des transports urbains en république démocratique du Congo, rapport final–Phase I, proposition de soluti.*

Pain, M. (1982). *Trente ans après la publication de l' Atlas de*

Kinshasa. Paris.

Plan, M. d. (2005). *Monographie de la ville de Kinshasa.*

Preferails. (2012). *Projet de construction du tramway de Kinshasa MALEBO. .*

S., B.-A. M. (1985). *Discrete Choice Analysis. MIT Press.*

Song. (1996). *Some tests of alternative accessibility measures: A population density approach. Land Economics, 72(4), pp. 474-482.*

SOSAK. (2014). *Schéma d'orientation stratégique de l'agglomération de kinshasa (sosak), sosak définitif (s4).*

Transurb Technirail, S. e. (2011). *Etude du Plan de Mobilité de Kinshasa, Rapport Final.*