Development of a Planning Support System for Public Transport Rationalization in Kigali, Rwanda

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Summary

This research tries to support the planning of public transport systems in a developing city, by proposing a GIS-based Planning Support System (PSS) to arrange and visualize data available for planning purposes. The PSS can help analysing various planning scenarios together with multiple stakeholders, to aid rational planning of the public transport system. The focus of this research lies on the transition of the current, often informal, state of public transport system to a formalised, planned and effective public transport system. The public transport system of Kigali (Rwanda) is used as a case study for the PSS development.

The main research objective of this study is to *develop a Planning Support System for the rationalization of public transport planning in Kigali, Rwanda.* To reach this objective, the concept of public transport rationalization is described in detail, followed by an analysis of the possibilities for rationalization of public transport planning in Kigali, Rwanda. A prototype PSS system is developed to aid this rationalization, and some recommendations for the further use of this system in rational planning are provided in a draft rationalization plan.

The concept of rationalization is divided in this research in three main definitions:

- *Rationalization-for-formalization* describes the practice of turning an informal transport system into a formal system, by increasing regulations and requirements for operators and interfering in the system planning.
- *Rationalization-for-efficiency* is a way of restructuring the system while making use of existing resources, by allocating them towards parts of the system where they provide higher financial or social returns.
- *Rationalization-for-decision-making* mainly describes a rational way of planning and decision making. Rational decision making is ideally not only based on experience and tacit knowledge, but also on reliable datasets, measurable results and clear planning targets.

These three definitions are used to advise the Rwandan government to rationalize their public transport system and its planning. To support governmental institutions in making these decisions in a rational way, a PSS is proposed that can help cooperation with multiple stakeholders.

A PSS is a software system that gives planners the opportunity to visualize their proposals on a map and to assess them with indicators and scenario analysis tools. These proposals often have a spatial nature, but transport planning can also be supported by the use of a specific PSS. The results of analysis in the PSS are mainly valid on a global system scale and should be validated on a local scale with the use of traditional transport demand and route choice models. A PSS can point out areas of interest for this further analysis and can be used to present the final results of such detailed analysis.

The indicators representing the adequacy of the system for passengers are based on the attributes Affordability, Availability, Accessibility and Acceptability. For each of these attributes, an indicator is chosen that is presented as a normalized score. All scores are summed in a general evaluation index, which can be used to define areas of interest for the improvement of public transport. Operators and government are served with indicators representing the size of the vehicle park, the total employment in the sector, the fare price and the total investment costs. This set of indicators can provide basic planning support, but can of course be supplemented by further research and availability of data.

Besides the development of the PSS, which can help planners and policy makers in Rwanda rationalize their own actions, this report has presented some recommendations for rationalization:

- Regulation of vehicle movements by introducing maximum waiting times and regulating the amount of vehicles per route
- Restructuring of the vehicle park by reallocating vehicles through the network and gradually replacing minibuses with larger vehicles
- Institutional reforms, especially by introducing an overarching public transport authority that can structure and connect planning and policy making.
- Encouragement of cooperation of operators for fare collection and distribution, which enables the adequate operation of financially less profitable routes
- Introduction of data-driven decision making in public transport as the standard practice in public transport policy making

The use of a PSS for public transport rationalization is a rather new research field, which has a lot of possibilities. This exploring research can therefore be used in further studies on the properties of rationalization of public transport in developing countries and the use of PSS to support this practice. As the characteristics of the Kigali public transport system are similar to other urban transport systems in Sub-Saharan Africa, this would be an area of interest for further use of the outcomes of this study.

Preface

This master thesis concludes my Master programme Civil Engineering and Management at the University of Twente, the Netherlands. It was conducted in cooperation with the Faculty of Geo-information Sciences (ITC) of the University of Twente and the Ministry of Infrastructure of the Republic of Rwanda.

I learned a lot during the writing of this thesis, both about doing research and about working in the context of a developing country. It has helped me put transport planning and engineering in developing countries into perspective, and has further enthused me for working in this field. I hope to write a lot more of these reports in the future, maybe from the Netherlands but hopefully also from somewhere abroad.

This preface allows me to thank some people who helped me, which I gladly do. At first, I would like to thank my daily supervisor Mark Zuidgeest. He interested me in sustainable transport in developing countries, during the minor Geo Data Processing & Spatial Information and the Master course Sustainable transport. He introduced me to the research topic and helped me figure out how to tackle the difficulties encountered during the research. Despite his busy schedule, he found time to read through my thesis and comment on it to make it fit in the tension between urban planning and transport. Our progress discussions in the ITC corridors were always motivating.

I also thank Prof. Eric van Berkum, who supported my slight deviation from technical transport engineering towards the practice of planning support for public transport. Although our contact was always brief, he has guided me well throughout this thesis and the rest of the Master programme.

During my field study, Dr. Mahabubul Bari has helped me with everything I needed, both in practical tools and in contacts with other experts. Even when I didn't always find the data that I was looking for, he helped me put my results into perspective, for which I can thank him now.

Other thanks go to Johannes Flacke, who introduced me to CommunityViz and allowed me to work with it, Alphonse Nkurunziza, who helped to make contact with Rwanda and supported me before and during the field study, Jean Claude Rurangwa and Deogratias Muvunyi, who have allowed me to interview them and query them for their data and Adrie Mukashema, who has helped me with practical means to do my field study. I further like to thank David Niyonsenga, whose dataset was very helpful in understanding the system during this study.

And finally, I thank my girlfriend Karin, family, friends of NSE (especially the "old bosses"), roommates of De Tempel and friends of Hoppa, who supported me during the creation of this thesis. You have all kept me both to and from my study in the last few years, which has helped me succeed!

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List of abbreviations

AMPH	AM (Morning) Peak Hour
BRT	Bus Rapid Transit
CBD	Central Business District
DSS	Decision Support System
EAC	East African Community
GIS	Geographical Information System
ITC	Faculty of Geo-information Sciences of the University of Twente (former International Training Centre for Aerial Survey)
KCC	Kigali City Council
MININFRA	Rwanda Ministry of Infrastructure
NISR	National Institute of Statistics Rwanda
NMT	Non-motorized transport
PAZ	Planning Analysis Zone
PMPH	PM (Afternoon) Peak Hour
PSS	Planning Support System
RNRA	Rwanda National Resources Authority
RTDA	Rwanda Transport Development Agency
RURA	Rwanda Utilities Regulation Agency
RWF	Rwandese Francs (1000 RWF ≈ 1.30 EUR)
SDSS	Spatial Decision Support System
TAZ	Traffic Analysis Zone
UT	University of Twente

Introduction

1 Introduction

The high pace of urbanisation in developing countries in the last years has led to an exponential growth of cities, often in unplanned new settlements. Combined with the economic development that takes place in urban areas, this leads to an increasing urban transportation demand. This starts with an increase in walking trips made, but quickly expands to motorized private and public transport trips as cities grow and distances increase (Gakenheimer, 1999). Most developing cities cannot cope adequately with this growing demand, which leads to deteriorated road networks and informal and inefficient public transport systems. This is partly due to a lack of funds, but also due to the difficulty of transport planning without reliable data about supply and demand.

According to Gakenheimer (1999) however, developing countries have many unique opportunities for making their public transport system more sustainable, due to the favourable climate for regulatory changes, the lower degree of convention on problem solving and the public consensus about the need for action. This makes developing the urban transport system an important focus for policy making in developing countries.

This research tries to support the planning of public transport systems in a developing city, by proposing a GIS-based Planning Support System (PSS) to arrange and visualize data available for planning purposes. The PSS can help analysing various planning scenarios together with multiple stakeholders, to aid rational planning of the public transport system. The focus of this research will be on the transition of the current, often informal, state of public transport system to a formalised, planned and effective public transport system. The public transport system of Kigali (Rwanda) will be used as a case study for the PSS development.

Chapter outline

Case study city Kigali is introduced and described in the first section of this chapter, after which the research background and motivation are described. This leads to research objectives and questions and a conceptual model. The research methodology is described using a research model and a description of the three methods that are used in this research.

1.1 Introduction to Kigali, Rwanda

Kigali is the capital city of Rwanda, a landlocked country in the East African Community (EAC). The country has 10.7 million inhabitants, of which 1.1 million live in the city of Kigali. This makes Kigali the largest city in the country, as around 90% of the remaining inhabitants of Rwanda lives in rural areas (National Institute of Statistics Rwanda, 2012). The last population census in Rwanda has been carried out in 2002, after which the city has grown significantly, but more recent figures can be found in other surveys.

Kigali is an individual province containing Kigali City and its surroundings. The province consist of 3 districts (Nyarugenge, Kicukiro and Gasabo), which are sub-divided in sectors, cells and imidugudu (the plural of "umudugudu", a term used to describe wards or villages, which are not used commonly as administrative entities). In the Kigali province, 83.6% of the population lives in urban areas. The Kigali City, which accounts for the main built-up part of the Kigali province, is the main focus of this report and will be further called Kigali.

Over 200,000 people migrated towards Kigali in the last 5 years, both from the rural provinces and from neighbouring countries. Of the in total 223.000 households, 62.6% are located in unplanned urban housing areas (National Institute of Statistics Rwanda, 2012). This large unplanned growth of the city has led to informal urban sprawl, which is one of the reasons why a lot of residential areas do not have paved roads and therefore no adequate access to transport systems.

Almost 500,000 people in Kigali City are working adults, of whom 53% are working on a wage job, 20% have an independent business and 23% are farmers. There is low unemployment, as most people who do not have a paid job are working at small-scale farms or are students. (National Institute of Statistics Rwanda, 2012).

Kigali City has a hilly topography, with most paved infrastructure and important landmarks built on the ridges of hills. Residential areas are built on hill slopes with wetlands unsuitable for building or infrastructure development between them. This limits the options for future land use planning and infrastructure construction.

Only the major roads through the city are paved. These roads, which are usually four-lane expressways, handle the heaviest traffic flows and are the only roads operated by the public transport system. The junctions are handled by roundabouts or traffic lights, which run static control programs that are not demand sensitive. In the peak hours most congestion occurs near the junctions, which requires them to be controlled manually by traffic police.

Public transport in Kigali City is operated by minibuses and large buses. There are no priority lanes or other priority measures for public transport. Another frequently used mode of transport is the semi-public motor-taxi, which is able to avoid traffic jams and offers door-to-door transport. There are no significant bicycle facilities in Rwanda and the bicycle is a rarely seen phenomenon in urban areas, although in rural areas bicycles are used both for private and semi-public transport. Motor-taxis and bicycles are not the main focus of this research, and in the rest of this report the term “public transport” will refer to the urban bus system.

1.2 Research background and motivation

The background of this research lies in the public transport systems of developing countries, and specifically in Kigali, Rwanda. This background is described through literature research and experiences during a field study in Rwanda and leads to the statement of the research objectives.

1.2.1 Public transport in developing countries

Informal public transport, often referred to as paratransit, accounts for an important modal share in many developing countries, especially in Africa, Asia and South-America. For the poorer population in these countries, it is an important addition to non-motorized transport (NMT) like walking and cycling. It fills the gap between often inadequate or deteriorated formal public transport and expensive private automobile ownership. The inadequacy of formal public transport is often caused by a historical failure to make state-owned systems profitable and the lack of resources to subsidize the systems (Sohail, Maunder, & Cavill, 2006). This has led to a decrease in the quality and safety of vehicles in the formal system, making the system less attractive to use. The characteristics of paratransit systems are however not only positive, as these informal systems often have negative side effects. It should for example be noticed that the failure of the formal system to reach profitability is also partly caused by the co-existence of paratransit, which makes this a paradoxical problem. (Cervero, 2000).

Paratransit can take several forms, from complete informality to semi-regulated systems. This distinction can for example be made on whether there are official standards, licenses or permits for drivers and vehicles, whether there are official lines or routes and whether there are official operating companies or cooperatives and fare structures (Cervero & Golub, 2007; Gwilliam, 2002).

Paratransit systems have often shown to be very effective in meeting real transport demand in developing cities, by allowing access to neighbourhoods poorly served by formal public transport and by being flexible to respond to market demand (Cervero, 2000). Self-regulation in informal systems on the other hand can just as quickly lead to a decreased match between supply and demand, because of the tendency to focus operation on routes that generate the highest profits (Kumar & Barett, 2008; Wipperman & Sowula, 2007). Paratransit also often poses a large threat to road safety and the environment, due to the lack of regulations on operation behaviour and maintenance and operation of vehicles (Cervero, 2000; Gwilliam, 2002; Sohail, Maunder, & Cavill, 2006).

Furthermore, the unplanned behaviour of informal transport tends to lead to problems with inner city congestion, vehicle overcrowding and accessibility for all inhabitants, and therefore has a negative impact on sustainable economic growth and development (Cervero & Golub, 2007; Gwilliam, 2002; Sohail, Maunder, & Cavill, 2006).

Because of the private ownership and small-scale operation, paratransit systems tend to generate a significant amount of direct employment, while public transport systems in general also enable a lot of people to reach other jobs and thus secure indirect employment (Kamuhanda & Schmidt, 2009; Gwilliam, 2002). This property is important to acknowledge, as changing the informal property of public transport systems might lead to negative economic impacts.

Public transport planning and formalization are therefore important governmental actions to improve the conditions for stable economic development, but only under specific conditions. This is acknowledged by governments in many developing countries, but the transition process towards a formal public transport system is not easy. One example of a system in transition is the public transport system in Kigali.

1.2.2 Public transport in Kigali

Kigali has a public transport system that can be described as semi-informal. It consists of a public bus system and a semi-public motor-taxi and "taxi-special" (taxi cab) system. The semi-public transport systems are not a focus of this study, but they are preconditions for the operation of the bus system, as they are used to fill the gaps in the bus system and even to replace the bus system at some times. By looking at the motor-taxi's for example, which are more than three times as expensive as and much more dangerous than the bus system but still operate profitably on the same routes, the preference of commuters for comfort and minimum delay are clearly indicated (Rurangwa, 2012).

1.2.2.1 Characteristics of the public transport system

The bus system has no clear timetable operation and no strict regulations on frequencies and the number of buses per route (Ministry of Infrastructure, 2011). There are dedicated licensed routes, which mainly focus on the high density areas around the Central Business District (CBD), the main governmental district and the airport. Most of them have not been planned in advance, but originate from "best practices" that were turned into licensed routes at a moment.

It is difficult for the government to get a good grip on public transport, because of the private ownership structure of the public transport operators. There are a few main operating companies or cooperatives, which operate the predefined routes with a large number of minibuses with around 17 seats each. There are currently around 900 buses (approximate figure reduced from RURA datasets) operating in Kigali, most of which are minibuses or coasters, which are slightly larger. Only one company operates a few large busses with room for up to 60 people. According to an independent research by Kumar & Barett (2008), minibuses accounted for around 75% of the modal share in Kigali at the time, which was in that research one of the largest percentages in sub-Saharan Africa. These minibuses are inefficient in their transport performance, because of their low capacity and their tendency to operate close together. This extensive use of inefficient minibuses (in terms of road capacity) leads to congestion on the busiest links that are used by many routes.

Most minibuses in Kigali are privately owned by their driver. These drivers sometimes operate their vehicles under the flag of a licensed cooperation, but most drivers are responsible for their own income. Because of profit optimization reasons, bus drivers would want to operate at full capacity and on the busiest routes. This leads to the common practice that buses wait to fill up before leaving the terminals, which leads to large uncertainty and possible delays along the routes in off-peak hours (Ministry of Infrastructure, 2011). During peak hours, the first few stops along the route are often not serviced, as all buses are already full when they leave the terminal.

In theory, there is a maximum allowed waiting time at bus stops along the routes, but this is not actively regulated or enforced by the government (Muvunyi, 2012). The informal, profit-driven type of the system leads to high spatial and temporal diversity in the public transport service, which in term introduces high uncertainty for users.

Other significant problems with the minibus public transport system are the low comfort inside the buses, the old age of the vehicles (which is often connected to higher emissions) and the lack of information about the operation of the system (Rurangwa, 2012). There is no fare per kilometre or zone travelled, but only per whole trip, although in some situations this might be negotiable. The standard trip price, which is paid inside the vehicle, makes transferring between buses relatively costly and difficult.

1.2.2.2 Planning and decision making

The mentioned operational problems make planners and policy makers want to create a shift from an informal to a formal public transport system. The system should be more efficient in using road space, more reliable for commuters and lead to better and more equitable accessibility for all citizens. For Kigali it would be especially beneficial to formalize vehicle types and their operation properties. This is also described in the report "Development of an Integrated Public Transport System for Kigali City" (Ministry of Infrastructure, 2011), which describes a formalization vision for the coming years.

The Ministry of Infrastructure (MININFRA, who is the main overarching transport authority), the Kigali City Council (KCC, whose Transport Department does most practical planning for the city's public transport system) and the Rwanda Utilities Regulation Agency (RURA, which is the agency issuing licenses to operators) are currently working on this vision by planning for new routes, limiting the issuing of new licenses to medium-sized or large buses and installing bus shelters. One of the long-term visions of the mentioned organizations is to develop a Bus Rapid Transit (BRT) system on the busiest routes, with dedicated lanes and a minibus feeder system.

On the short term however, intermediate solutions should be introduced to keep the system both profitable and equitable. The informal sector provides necessary transport to the lower and middle income classes in Kigali and employment to a lot of people. In the rationalization process, it would be better not to replace all minibuses at once, but to make use of existing resources, like infrastructure, operators and vehicles, while gradually changing to a more formal system with larger operating vehicles and better schedules.

The service oriented transition process described above is often called *rationalization*, a term that will be used throughout the rest of this report. This rational way of looking at planning is however not always chosen in Rwanda. The low availability of data and the high degree of individual knowledge and experience lead to policy decisions that cannot be checked with facts adequately. Many decisions are made top-down without proper research into the pros and cons of policy implementation.

Public transport planning in Kigali is typically done by a small group of experts, who rely on knowledge and experience on the ground and simple numeric calculation methods. When more complex transport models are required for planning, their development and operation is often outsourced to external consultancy parties. Transport models and knowledge about them are therefore not readily available to planners, although plans are made to procure models in the future. In the meantime however, public transport planners would be helped with a planning tool that helps organizing data that can be used for planning. This would ideally start from the current practices and available data, with the opportunity of professionalizing the planning process in the future.

For the actual introduction of measures in the public transport system, the planning experts usually provide their knowledge to a group of decision makers that consists of policy makers from various government organizations. Each organization has its own data and expert opinions, and decisions in stakeholder meetings are often made based on negotiations and compromises that do not necessarily lead to optimal policies.

This policy making process in Rwanda would therefore be helped by a system that can support stakeholder meetings by providing an overview of all data and a clear interface, to streamline decision making. This support system should not provide technically complex solutions, but should be understandable and easy to operate for non-expert policy makers.

1.3 Research rationale

The effort for rationalization and the requirement for practical planning tools described in the previous section is the main motivation for this research. These two needs of planners and policy makers can be served by the creation of planning support software and the definition of a rationalization plan.

A combination of a system for planners and policy makers, which would not focus too much on detailed transport modelling but rather on data combination and visualization, would fit perfectly in the current planning and policy making practice in Rwanda. Users will not specifically value the detailed analysis that microsimulation provides, as they do not have direct access to these data at this moment either. They would rather use a system that fits their current knowledge and fulfils their need for clarity and overview of data. These basic needs and requirements are known from interviews in a field study, and are further clarified and elaborated on later in this report.

This research will focus on developing a prototype GIS-based support system for planning and policy making actions, based on the needs for such a system in Kigali. This system will be referred to in this study as a Planning Support System (PSS), which will be further defined and compared with standard transport models later.

The use of a PSS and the principles of rationalization will help planners and policy makers to make a paradigm shift from ad-hoc decision making to data- and scenario-based, rationalized decision making. This research will describe the requirements for this change of practice.

The development of the PSS in this report requires in-depth research into the concepts of rationalization, public transport planning and planning support systems. The current organization of public transport planning in Rwanda (and especially in Kigali) is reviewed, to determine the possibilities for offering planning support in the present planning fashion.

1.3.1 Objectives

The topics described in the previous sections lead to the formulation of a research objective. The main objective of this study is:

To develop a Planning Support System for the rationalization of public transport planning in Kigali, Rwanda

This main objective is reduced into sub-objectives:

- *To develop an understanding of rationalization of informal public transport.*
- *To describe the current way of public transport planning in Kigali and the requirements for planning support.*
- *To define the properties of a support system for public transport planning and policy making.*
- *To develop a prototype support system that can help rationalize planning in Kigali.*
- *To make recommendations on the use of such a support system for rationalization of public transport in Kigali.*

These research objectives describe the academic and practical goals of the study. Their results will be interesting for public transport planners and policy makers in Kigali, who can use the system in their daily work, but also for academic researchers both in and outside Rwanda. The concepts of rationalization, planning support and public transport planning in developing countries will be combined, which leads to possibilities for further research into these topics in Rwanda or in other contexts.

1.3.2 Research questions

The research objective will be achieved by answering the following main research question:

How can a Planning Support System guide the rationalization of public transport planning in Kigali, Rwanda?

This main research question and the mentioned research objectives lead to the following set of research questions:

1. *How can the concept of rationalization help the formalization of informal public transport in developing countries?*
2. *What is the current fashion of public transport planning in Kigali?*
3. *What are Planning Support Systems and how can they be used for public transport planning?*
4. *How can the public transport system be evaluated and scored in a Planning Support System?*
5. *What are specific requirements for a Planning Support System for Kigali?*
6. *What are important areas of interest for rationalization of public transport in Kigali?*

These research questions will be answered through literature research and a field study and they will lead to the development of a prototype Planning Support System.

1.3.3 Conceptual model

The research motivation and rationale are summarized in the conceptual model for this research in Figure 1. This model describes the way towards rationalization of policy making, from ad-hoc to rationalized policy decisions. This is reached through the evaluation and scoring of the public transport system characteristics in a PSS, the testing of scenarios based on the principles of rationalization and the translation to policies in a rationalization plan. This process will be run through in this research, although it is only an example and prototype for the use in reality.

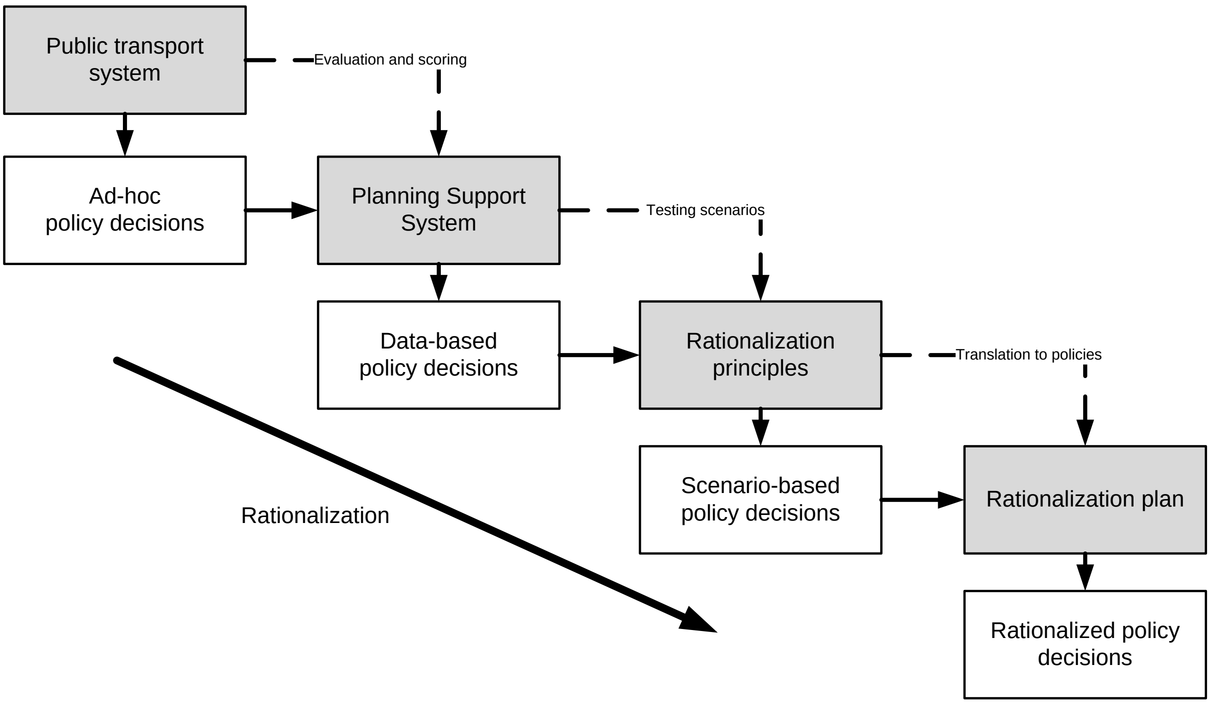

Figure 1: Conceptual model

1.4 Research methods

This research will connect literature research, experience from the field and practical software development in the office. This combination is made in an iterative way, starting from the research proposal, which consisted mainly of literature research. After introduction to the software, a field study was conducted, to gather practical experiences from experts in Kigali and determine their needs and requirements. This is confronted with literature again and implemented in a conceptual software design. This software will be submitted to experts in Kigali again to complete this cycle.

1.4.1.1 Literature research

The theoretical framework of the report describes the experiences with public transport rationalization and the use of PSS in earlier research. These experiences are mainly selected from other researches considering developing countries and especially Sub-Saharan Africa, as they are more similar to the context of Kigali. Literature considering Asian, South-American and European practice is however also reviewed.

Theory about public transport planning and evaluation, which led to a full range of evaluation indicators for use in the PSS, is also described in the theoretical framework.

1.4.1.2 Field study

Starting from the experiences described in literature, this report further elaborates on the potential of public transport rationalization in developing countries, and especially in Rwanda. This discussion is based on encounters with the planning practice in Rwanda and discussions with local experts during a five-week field study in Kigali in the beginning of this research.

During the field study, several discussions and interviews were undertaken with local planners and policy makers, to be able to deduct the requirements for a PSS in public transport planning. This has led to various insights on which indicators should be implemented and evaluated to be able to provide good planning support.

The field study was also used to collect data from the various planning institutions in Rwanda. Because most available datasets were gathered from all major stakeholders, a clear overview of the available knowledge and experience can be deducted. The datasets are used to describe the current public transport system and to allow for the implementation of scenarios.

1.4.1.3 Software development

The knowledge and experience gathered from the literature research and the field study is combined into a prototype PSS, created in ArcGIS extension CommunityViz. This required some research into the possibilities the software offers for public transport planning and interactive planning support, which had to fit the needs of the users in Rwanda. A basic PSS interface was created, after which the characteristics of the Kigali public transport system were implemented.

Multiple evaluation indicators, based on developed conceptual models, were programmed into the software to create a working PSS prototype. Special attention was paid to the goal of making the PSS user-friendly for both experts and non-expert users.

The users of the PSS, which are clearly defined into three groups in this report, get the opportunity to create scenarios, which can be used to evaluate proposed policies. This can be done through the use of predefined variables, but also by implementing their own data and knowledge.

The prototype PSS is used mainly as an example of the use of PSS in the area of public transport planning. It is not fully functional, but can be extended to be applied in practice in Kigali.

1.4.1.4 Research model

The above research methods are presented visually in the research model in Figure 2. It shows the input theory and data from the field study to the left, resulting in the research perspective of public transport evaluation indicators and their confrontation with the public transport system. This confrontation will be described in a PSS using the GIS-application CommunityViz. The scenario analysis and draft rationalization plan are created using this PSS and the knowledge of rationalization.

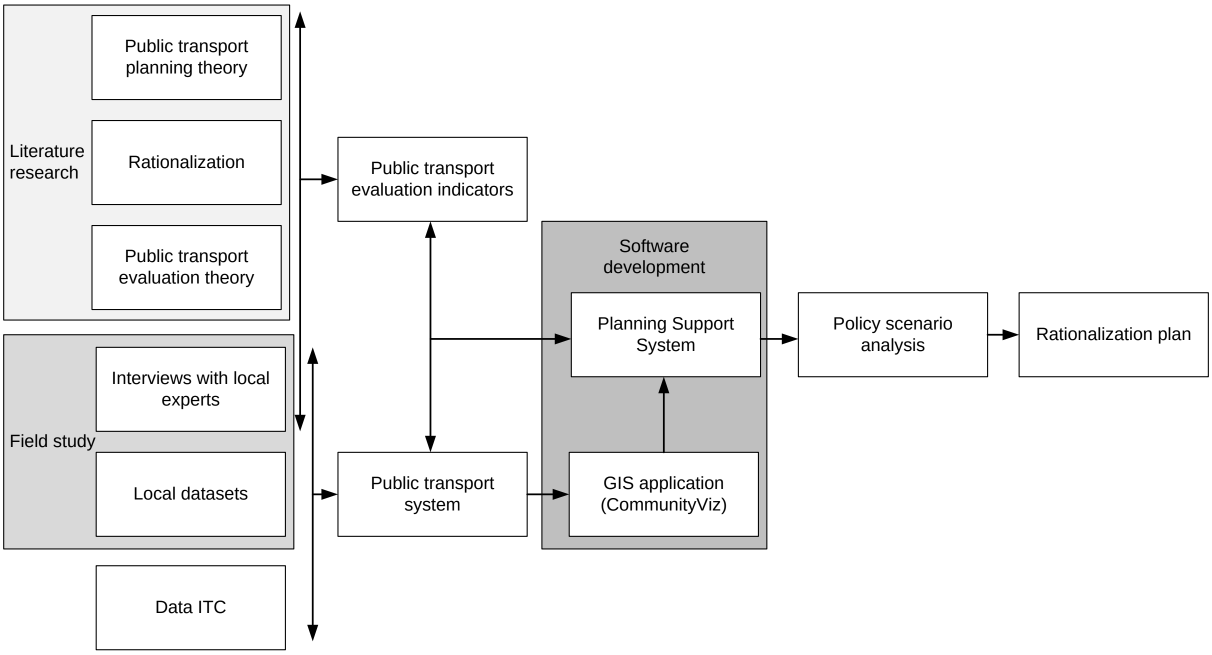

Figure 2: Research model

1.5 Report outline

In Chapter 2 of this report, the theoretical framework of the study is described, especially concerning the concept of rationalization, the use of Planning Support Systems and the assessment of public transport systems. Chapter 3 is a report of the data collection process, which mainly took place during a field study in Rwanda. The theory and datasets are confronted in the development of the PSS and the definition of policy scenarios in Chapter 4. Using the knowledge gained during this research, some recommendations for public transport rationalization in Rwanda are provided in Chapter 5 in a draft rationalization plan. Chapter 6 is the conclusion of this report and summarizes the results of the research and recommendations for further research and further use of the PSS.

Theoretical framework

2 Theoretical framework

The theoretical framework consists of theory on the concept of rationalization, Planning Support Systems and the assessment of a public transport system. This theory was composed using reference to literature, added with experiences and interview results from the field study. The latter are presented as data sources in Chapter 3, but are already mentioned through references in this chapter.

Chapter outline

In the first section of this chapter, the rationalization concept is described in three distinct definitions, which are related to the public transport planning issues in Rwanda. The characteristics of a Planning Support System and the potential for application in transport planning are mentioned in the next section, leading to the proposal of a PSS for this research. The assessment of the public transport system, which is based on the relations between demand and supply, is mentioned in the third section. This section also mentions the different user groups and explores which indicators should be used to evaluate their stakes

2.1 Rationalization of public transport systems

Rationalization is a buzzword, often used in combination with developing countries and public utilities. The term is used in many sectors, ranging from energy to trade, but this report focuses on the use connected to urban public transport.

The word rationalization is used in various meanings and for multiple purposes and is therefore an ambiguous term. The broad scope of definitions often makes the popular discussion about rationalization unclear, as it is not always known what actions are meant by the term. Clear definition of the concept is therefore important. In this research, the various concepts of public transport rationalization are therefore aggregated in three new definitions: "*formalization*", "*increasing efficiency*" and "*systematic organization of decision-making*". These three terms have very different definitions and should therefore not be mixed, but they can be used side-by-side in most situations, as will be seen in this report. The three definitions of rationalization are described shortly in this section, and are used throughout the rest of the report.

2.1.1 Rationalization-for-formalization

Some researchers use the word rationalization as a synonym of "*formalization*", the reduction of informality in the system, which often goes hand in hand with government interference and regulation (Lomme, 2008; Wipperman & Sowula, 2007). Wipperman & Sowula (2007) use the development of public transport in London as an example for this need for formalization. The first underground metro lines in London were developed as private ventures, but as the city grew the government had to interfere and invest more and more to ensure that that the metro network grew in the same pace. Private operators tend to optimize for their own profit and will not invest easily in the less profitable parts of the network. Because these investments are however important for the overall growth of the city, the economy and the society, the government needs to formalize and structure, or even de-privatize, these operations. This formalization also enables the introduction of regulations and requirements for the operators, where there is no ground for this in a completely informal market.

Ahmed (2004) describes such a rationalization-for-formalization vision by the South African government, in which the Western Cape minibus-taxi industry is reformed trough formalization and regulation. This is a complete package of measures, with practical solutions for the short term and extensive visions for the long term.

Lomme (2008) however looks back at the same formalization practice in South Africa. In their urge for formalization, the government institutions attempted to scrap the whole minibus taxi fleet to replace it completely by new vehicles. This attempt is questioned by Lomme, who argues that complete and sudden formalization is not always the most efficient approach. Gradual formalization and even operational integration of informal transport seem more sustainable options to him.

This way of looking at the term rationalization focuses therefore at *the restructuring of regulation and enforcement to turn an informal public transport system into a formal system*. There are many ways of doing this, ranging from complete and sudden formalization to sector-aimed and gradual formalization.

Which approach should be followed and to what extent formalization would be advisable varies for every context, and is therefore an important focus of rationalization-for-formalization. This should be evaluated in the light of rationalization-for-efficiency and rationalization-for-decision-making.

2.1.2 Rationalization-for-efficiency

Some studies like to think of rationalization as "*a rational way of operating*", for example by focussing more on planning and (cost) efficiency (Cervero, 2000; South Africa National Department of Transport, 2001). Rationalization was defined by Mason (1980) as:

"A reallocation of resources away from unproductive activities to areas which yield higher private and social returns".

The concept is used here to describe the transition of existing, often unplanned, public transport to more efficient planned public transport, by eliminating inefficiencies in the network, restructuring contracts and making the system more cost efficient (South Africa National Department of Transport, 2001). According to Mason (1980), this could mean that some ineffective or unproductive services or routes should be eliminated to focus on making system more effective, based on the demand in the area and the service on all routes.

Which parts of the system are signalled as ineffective depends on the policy decisions that are made. These could range from making the system as profitable as possible (which would be the scope of individual operators and which would focus on routes along the busiest areas), to making the system as equitable as possible (which would also focus on serving the population of suburbs and would lead to a more differentiated system). Other policy choices could try to minimize pollution caused by congestion, limit the amount of vehicles in the system or favour specific areas or population groups.

This definition of the rationalization principle focuses on *restructuring the system based on planning rather than ad-hoc operation.* It focuses mainly on rationalizing *what you plan*. Whether this rationalization is in the end more efficient than ad-hoc, demand-based operation is however arguable, as more planning could also make the system inflexible and receptive to delays. This is largely dependent on the goals of choosing this rationalization approach and the environment it is implemented in.

2.1.3 Rationalization-for-decision-making

Rationalization is also seen as the practice of basing the system on reasoning, criteria and scientific research (Cervero, 2000; Niger, 2011). The policy decisions made in the rationalization-for – formalization and rationalization-for-efficiency processes should be aided by clearly presenting and reviewing the results of all decisions. This process enables *rational decision making*, based on clear planning goals and reliable data. This is therefore a different view at the term rationalization, which can be redefined for this context with the following working definition (based on Mason, 1980 and Niger, 2011):

"A reallocation of resources based on measurable effects and planning targets"

This rational way of dealing with planning and policy making focuses on rationalizing *how you plan*. This rationalization in itself is not the goal of a planning action, but it is rather *a way of structuring the planning and decision-making processes*. It can be important to systematically organize these processes, as there are often many different stakeholders and planning actors involved, who each have their own knowledge and data. When not adequately organized, this can lead to endless discussions in the decision-making process and inefficient planning results.

2.1.4 Need for public transport rationalization in Rwanda

Public transport planning in Rwanda is done by a few distinct governmental organizations, which were mentioned in section 1.2.2.2. They have their own responsibilities, ranging from the development of master plans, via the licensing and regulation of operation to the construction of roads. Each organization has its own sub-policy plans and collects its own data or uses data provided by third parties. Most data is however not up-to-date, incomplete or lacking metadata. The alignment of different sub-policies is poor and cooperation between organizations is difficult. Most important decisions are made in multi-stakeholder meetings, which consist mainly of discussion and bargaining about each organization's stakes. These meetings are not always founded on clear data or estimations of results. (Rurangwa, 2012; Muvunyi, 2012)

This practice would therefore be helped by all three mentioned ways of rationalization:

- The processes of *rationalization-for-formalization* could guide the ambition of the government to formalize the public transport system. It should be determined if sudden and complete formalization is the best formalization policy, or if gradual formalization is a better way to go.
- *Rationalization-for-efficiency* in Rwanda would focus on the possibilities for reaching higher productivity of the current public transport routes. This could include restructuring the physical routes and their vehicle operation, but also reforming institutions, operator contracts and fare pricing structures.
- This process should happen in the light of *rationalization-for-decision-making*. The current way of planning routes and bus stops, assigning buses to routes and applying frequencies to routes could be changed in nature, from operator-based and free market-based to quality-based and target-based planning. This is currently a major shortcoming of the public transport planning, where multiple stakeholders maximize their planning efforts towards their own interests and according to their own datasets. Channelling these efforts in an effective way would almost certainly lead to higher social returns. This form of rationalization could also address the current set-up of organizations concerned with planning public transport and the planning tools they use.

2.2 Planning Support Systems

As Hernandez & Witter (2010) describe, normal transportation planning tools are not always capable of assessing the complete spectrum of transport problems in developing countries. Traditional transport models often base their predictions on high quality data, specific knowledge and clear planning settings, while these are not always present in a developing context. Poor data quality is caused by the unplanned growth of developing cities, the large role of the opaque informal economy and the lack of specific data collection and processing.

Traditional planning tools should therefore be supplemented with social data, personal experience and visualisations to be able to rationally evaluate the decision making process in these countries. An important group of tools used for combining these different types of data and knowledge are the Planning Support Systems.

2.2.1 Introduction to Planning Support Systems

Planning actions, like the introducing of new routes, larger vehicles or better operation schedules, have effects on both the public transport system and the land use in the area it serves. They could for example lead to an increase in accessibility of certain areas and enlarge the transport performance of routes. The decision to introduce such improvements is usually made by political decision-makers. They often have a pure political rather than a technical background and are often not adequately informed about the details of all possible policy options, although they have to make decisions to implement them.

According to Vonk, Geertman & Schot (2007), this kind of decision-making by politicians should therefore be preceded by a set of planning steps. These steps are usually the *problem definition*, the *exploration and analysis of the problem* and the *definition of possible future changes*. In some planning processes, *consultation* or *collaboration* is added as an extra step, in which other stakeholders are involved in the planning process (Vonk, Geertman, & Schot, 2007). In this research, the main focus lies on the exploration and analysis of problems and the definition of possible future changes, done in collaboration with multiple stakeholders. This planning process takes into account a lot of different users, stakes, interests and information and is often ill-structured. To structure this process and bring valuable information together, a Planning Support System (PSS) can be introduced in the planning process.

2.2.1.1 SDSS and PSS

Rationalized policy decisions have desired effects, which should be validated before actually introducing the policy measures in the field. Proposed changes in public transport supply for example, have to be guided to be able to define areas of interest and to make optimal use of the current resources. This requires a policy scenario analysis, which can point out the most promising scenarios for public transport rationalization, given certain targets. A good tool to analyse the effects of interventions on these objectives is a Spatial Decision Support System (SDSS) or Planning Support System (PSS).

SDSS and PSS systems are Decision Support Systems (DSS) with a spatial component. They are developed to support public or private planning processes that have spatial components, especially to support the derivation of alternative futures (Geertman & Stillwell, 2003). They are used to combine available *data*, analytical *models*, *expert knowledge* of decision makers and graphical *visualisation* into a framework which can guide decision making processes. This is represented in

Figure 3 (Boerboom, 2010), which shows the added value of a SDSS or PSS model at the top, supported by descriptive models and simulations (transport models) and data.

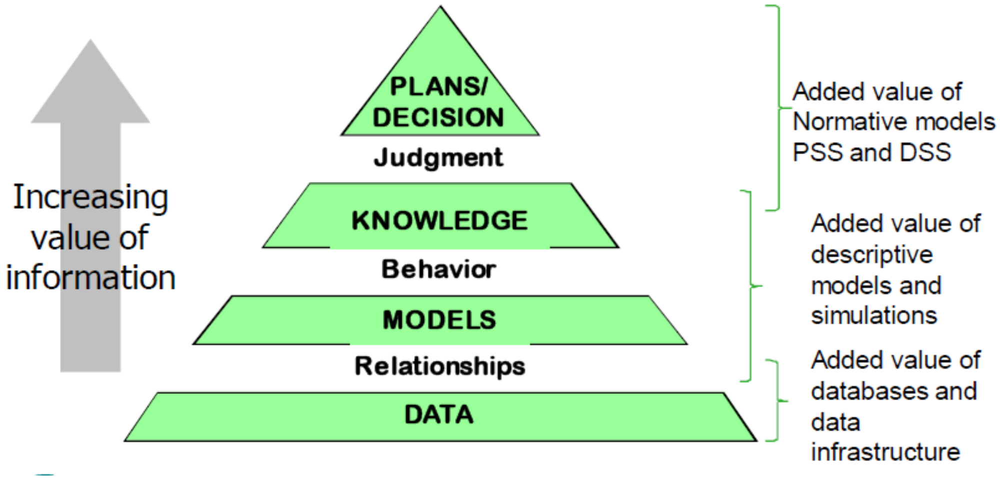

Figure 3: Information pyramid representing the added value of PSS (Boerboom, 2010)

SDSS and PSS systems are often developed as task-specific systems to solve ill-structured problems. They usually distinguished by their target, which is either to support short-term decision making by individuals or governmental organisations (SDSS), or to solve long-range strategic problems, possibly by allowing multiple stakeholders to join in the process (PSS) (Geertman & Stillwell, 2003).

In this research, a basic system will be developed which could be used in both short-term and long-term planning and decision-making. It is built for policy makers, but could on the long run also be used to invite other stakeholders to join in the planning process (the collaboration step). In the remainder of this research, we will refer to the hybrid form between the two systems simply as a *PSS*.

In the next three sections, some extinct characteristics of a PSS model are mentioned. These make clear what the main advantages of a PSS are for users in a planning context.

2.2.1.2 GIS-based structure

A PSS can facilitate policy making and planning, by calculating the effects of intended policy scenarios on selected indicators. A PSS system built in a GIS environment can easily visualize these effects on a map, clearly identifying affected areas and spatial opportunities for further development. A fully interactive PSS can display effects directly on the map based on variable parameters, which gives a clear overview of the direct effects of any policy, even when the user is not a GIS expert (Esri, 2012). A main advantage of using a GIS-based PSS is that all available datasets can be structured in a clear and complete database management structure. There is no minimum amount of data required, which enables the technique to be used in the context of developing countries that usually have less data available for planning purposes (as mentioned earlier).

2.2.1.3 Knowledge structuring

When people meet to engage in collaborative planning, conflicts arise because they have different sets of knowledge available to them. Part of this information can be defined in data, but another part is available only in personal experience or intuition. Te Brömmelstoet and Bertolini (2008) call on sources from the knowledge management field when they define these knowledge types respectively as “explicit” and “tacit”. *Explicit knowledge* can be expressed in words, values or indicators, while *tacit knowledge* can only be expressed in specific situations, for example in discussions.

A PSS system can structure the knowledge of collaborating planners by enabling them to both implement their individual explicit knowledge (datasets they own or information they have) in indicators, and use their tacit knowledge to judge the values of these indicators. The use of PSS challenges them to display both types of knowledge to each other and bring it to the discussion table, which, inevitably results in better products.

2.2.1.4 Complexity vs. understanding

Te Brömmelstoet and Bertolini (2008) make clear that there is a paradox between complexity and understanding in PSS development. A model should be able to represent reality good enough to convince planners to use it in their practice. PSS models should therefore contain as much data as possible and available about the system and should combine these data to compose useful indicators that represent reality correctly.

PSS models and their representation of data should however also not be too complex. Planners must be able to understand the underlying assumptions, which enables them to learn from the model and use it to create new strategies. According to te Brömmelstoet furthermore, it is more often found that practitioners are looking for “redundant approximations” than for “detailed models” (te Brömmelstoet, 2010), which points out the preference of clarity of representation over quality. Te Brömmelstoet mentions the lack of transparency, user-friendliness and interactivity as the main potential bottlenecks for successful implementation of a PSS, while specificity, credibility and costs are much less important barriers (te Brömmelstoet, 2010).

This paradox is also evident in this research. The PSS development described in this research aims mainly to create understanding of the system for non-expert policy makers and clear communication of data for planners, as represented in the information pyramid in Figure 3. Because the more complex (lower in the pyramid) transport modelling in Rwanda is outsourced to external consultancy companies, the underlying principles of these models are not available for modelling in the PSS at the moment. Further development of the PSS could however be done in cooperation with these consultants, to allow the introduction of more complexity from transport models and better representation of reality, while keeping the interpretability high.

2.2.2 Application of PSS in public transport planning

The explicit use of a PSS for public transport planning is not very common, as planners often tend to describe a transport system in transport models, like demand, route choice and microsimulation models (the middle layers in the pyramid in Figure 3). PSS are typically used for addressing pure spatial urban planning elements, like spatial development of certain areas or suitability analysis studies. When transport is implemented in PSS, it is often included as a supporting or driving attribute for land use development changes (for example in a cellular automaton system like Metronamica (RIKS, 2011)) or used for pure physical planning (for example in the study of Keshkamat, Looijen, & Zuidgeest (2009)).

The properties of PSS with a spatial approach can however be valuable for public transport planning, as it gives its user the opportunity to *quickly review the expected global effects of policies*, without the direct interference of complex simulation models and with the opportunity to use experience and tacit knowledge. Although this reduces the reliability and detail level of data, it is useful for global policy making as a set up for more detailed evaluation by experts (the top of the pyramid in Figure 3).

A PSS model can often cope with different growth scenarios and provide clear and interpretable results. These results are usually presented in indicators that can be designed to be interpreted by non-expert users. These users are often confused by technical simulation model results, which makes them rely heavier on the preparation by transport experts and indirect results generated by models. Transport experts are not always readily available in developing countries and in small governmental organizations, and are in their turn often not familiar with operating in a decision-making context. The use of PSS could therefore help in *making the communication between technical planners and political policy makers more transparent and fluent*.

As mentioned earlier, a PSS is furthermore *not as sensitive to data quality* as for a traditional transport model, and is therefore useful for planning in developing countries, that often do not have access to data with high quality and detail level. The use of PSS in public transport planning could give planners in these countries access to *affordable tools to rationalize their planning process*.

GIS based PSS systems can efficiently manage different data formats that can be stored and used efficiently. This especially concerns spatial data, but the internal network components in GIS applications like ArcGIS also allow for some transport and network analysis. The clear user interfaces and good graphical representation of results make a GIS based PSS much more *applicable for decision making during meetings with various stakeholders* and politicians than traditional transport models. (Arampatzis, Kiranoudis, Scaloubacas, & Assimacopoulos, 2004).

The *coarse scale of a PSS* and the *generalized results of the analysis* are the main downsides of using a PSS for transport planning analysis. Furthermore, the *behavioural effects* of people cannot be modelled in the PSS, sometimes resulting in too positive or negative effects. Actual implementation of policies should therefore be preceded by more detailed analysis in traditional transport models, for which the PSS points out areas of interest. Data originating from demand, route choice and micro-simulations could also act as input for the PSS or could be reviewed parallel to the PSS analysis.

PSS models are especially valuable when an important planning issue is the interaction between transport and land use development. Te Brömmelstoet & Bertolini (2008) further argue that PSS systems have the potential to be really valuable especially for combined land use and transport planning, which is often an unstructured process due to conflicting approaches of planners.

The use of PSS for transport planning is acknowledged by Arampatzis, Kiranoudis, Scaloubacas, & Assimacopoulos (2004), who have developed a prototype transport PSS for the Greater Athens Area in Greece. Their PSS can be used to efficiently evaluate public transport developments with respect to demand, fuel consumption and air pollutant emission. The tool they describe is however very specific and especially designed for this research, which makes it hard to reproduce for many different areas. More tools will however become available when PSS becomes more widely accepted in transport planning. This report tries to display the potential a bit further to speed up this process.

2.2.3 Potential for PSS in Rwanda

Rwanda is economically developing and professionalizing rapidly, which enlarges the demand for modern systems in the planning and decision-making process. Meeting rooms are equipped with beamers and presentation screens and planning departments have access to computers with ArcGIS software. This infrastructure is therefore appropriate enough to introduce digital tools that can support the planning practice.

The potential of GIS as a decision and planning support system is acknowledged in Appendix 6 of Rwanda's National Land Use and Development Master Plan (Rwanda National Resources Authority, 2010), which describes the vision for creating Urban Development Plans using GIS-based decision support. The appendix describes a step-wise plan for the introduction of such a PSS in urban (transport) planning. The report calls data management, user-friendliness, political and planning transparency and monitoring characteristics of a PSS positive and very desirable for future development plans in Rwanda. This opens great possibilities for the PSS proposed in this report.

The use of GIS tools for planning support in Rwanda is also acknowledged by the National Institute of Statistics Rwanda (NISR), which are currently cooperating closely with ArcGIS publisher ESRI in the enrolment of the 2012 General Population and Housing Census. On the website of ESRI, government officials speak very positively about the transparency, visualization techniques and planning and decision support of GIS (ESRI, 2011). It is very likely that the government will keep this focus on GIS databases, providing more potential for the transport PSS proposed in this report in the near future. This is further strengthened through the effort done by ESRI to educate more students to use GIS tools through their local branch ESRI Rwanda (ESRI Rwanda, 2012).

From the sources above, it is therefore clear that the development of a GIS based PSS is driven by demand from the field and is important for further development of the sector. A PSS, filled with datasets from all stakeholders and equipped with scenarios, could help *structure and rationalize the public transport planning meetings* described earlier. *Structuring, aligning and warehousing of all available data* with a *clear interface* would make the decisions between stakeholders a lot more transparent and effective, favouring the process of rationalization-for-decision-making.

Rationalization-for-efficiency would also be increased by the introduction of a PSS, as the productivity of public transport routes can be monitored easily and plans for restructuring the system can be evaluated with indicators. This would focus on the policies that have a spatial component, as the restructuring of institutions and contracts would not be feasible to evaluate in a PSS.

As is described in the recently published report on Development of an Integrated Public Transport System for Kigali City (Rwanda Ministry of Infrastructure, 2012), the government of Rwanda favours the involvement of as many stakeholders as possible in planning for public transport. In a "bottom-up" and "public participatory" approach, they express the need to involve the community as much as possible in every step of the planning process. The use of a PSS in every step of the planning process could be very helpful to promote this community participation, as rationalized decisions can be presented in a very transparent way, including the results of various possible scenarios. In Figure 4, a model from the report representing the anticipated bottom-up planning steps is adapted to show the planning steps in which PSS could be of important help. This is both in the execution of the planning process from the establishment of goals to the assessment of alternatives, and in the involvement of different stakeholders in this process.

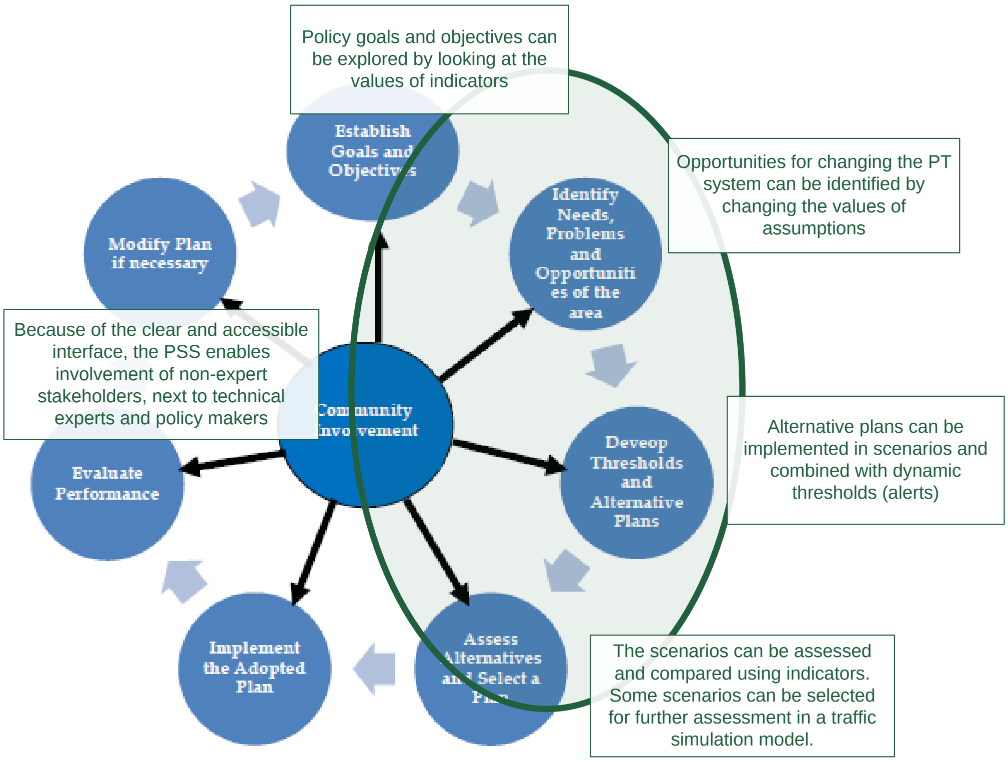

Figure 4: Importance of PSS to aid the bottom-up public transport planning and decision making process (adapted from Rwanda Ministry of Infrastructure, 2012)

As discussed earlier, the current public transport planning and policy-making practice in Rwanda focuses on the development of basic policies. The detailed elaboration on these plans, including technical modelling in transport models and effect analysis of solutions, is outsourced to consultants from abroad. The main goal of the PSS is to support the current policy-making process. The PSS should therefore focus on basic planning actions that do not require detailed modelling and analysis by experts. The results of technical analysis by consultants could however be incorporated into the PSS by involving consultants in the use of the PSS for planning and policy making.

2.2.4 CommunityViz

The GIS environment that will be used for creating the PSS is CommunityViz, a decision-making software tool developed by Placeways LCC. CommunityViz is a set of extensions to the ArcGIS software. ArcGIS is software used commonly in planning departments in Rwanda and is therefore common to most users. CommunityViz is easy to operate for users familiar with ArcGIS and the basic operation can also be learned easily by non-experts.

The extra feature of CommunityViz over normal GIS tools consists of the availability of “assumptions” that can easily be adjusted by users. The values of these assumptions can be used in formulas or as dynamic values, which give users the ability to influence the data interactively. Assumptions can be combined in “scenarios”, which can be compared to each other as complete policy measures. The other main functionality that defines the PSS capabilities of CommunityViz is the ability to output indicator values, which can be used to evaluate of the different scenarios. These indicators can be prepared by expert users and can be reviewed by non-expert users of the PSS.

The computational relations within CommunityViz are displayed in Figure 5, which gives the graphical workflow presented by the tool itself. Static input *data* can be combined with the dynamic inputs of users, the *assumptions*. Together they form *scenarios*, which are evaluated by the *indicators*. Indicators mainly evaluate the *dynamic attributes*, because they are the values that are changed by assumptions. The end-user can request CommunityViz to output results, either in the form of *alerts* (warnings that threshold values of indicators are reached), *charts* (that give an overview of the values of indicators for different scenarios) or *reports* (that are merely a textual output of these values). The first judgement of non-expert users will also require visual information. Most indicator values can therefore be presented to the user directly on the map view.

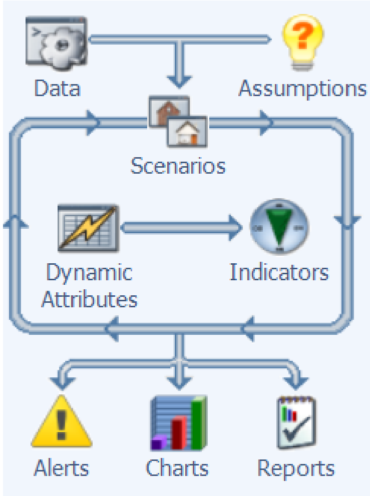

Figure 5: Main workflow of CommunityViz

The software adds a user-interface layer over the data, which is gathered in an ArcGIS database. The user interface consists of two screens. The first and most extensive view can be used by experts to implement assumptions, indicators and functions combining these two with existing datasets. A second view, which is the real end-user interface, can be used by policy makers to adjust assumptions and review indicators in a clear and user-friendly way.

CommunityViz toolbox “Scenario 360”, which is described above, is an analysis tool that is typically able to evaluate the effects of different land use scenarios and visualize the results of this analysis on a map. These scenarios are easy to adapt and can consist of various indicators and weights. Because the formulas in the software can be created by any moderate GIS expert, this software can easily be adapted to be used as a PSS for public transport evaluation, especially when the scope is mainly focussed on land use related effects.

In the toolbox “Scenario 3D”, the environment of the PSS can also be explored in 3D. This could be useful for specific discussions about areas, and could in the future be expanded with planned land-use developments to present policy actions to a wider public.

2.3 Public transport assessment

Public transport service and operation is defined by the total demand for public transport in an area and the physical supply (level of service) that is offered by the public transport system. The demand, which describes the amount of trips that are made or can be made, is hard to grasp and is often based on estimations and models. The physical supply can be measured and described in a more analytical way, as it consists of the network with bus routes and stops, the vehicles operating on this network and the people and resources that are required to operate them.

The match between public transport supply and demand can be measured with evaluation indicators that are of interest to passengers, operators and the government. They can be used to define the quality of the system and can point out areas of interest for expansion policies.

2.3.1 Public transport demand

The demand for public transport can be estimated using the traditional four-step demand estimation model. This model, which consists of the steps *trip generation, trip distribution, modal split* and *traffic assignment,* describes the demand for transport on all modes. The trip generation describes which locations have the potential to generate trips, based on personal characteristics of people. Trip distribution and modal split describe how these trips are distributed between all origins and all destinations and with which modalities they are likely to be made. Trip assingment focusses on the exact routings of these trips on the network. (Vuchic, 2005; Ortúzar & Willumsen, 2001) The modal split step will not be elaborated on in this study, because all datasets used are concerned with the public transport mode.

2.3.1.1 Demand estimation

Trip generation and *distribution* estimates in this study are done by basing them on observed trips. An extensive survey study was done by SSI Engineers prior to this research, in which specific questionaire surveys and full traffic counts were combined into OD-matrices that represent the estimated amount of trips between all zones (SSI Engineers, 2011). This combination was created in a traffic simulation model that is not available for use in this study and the matrices cannot be verified or reproduced. The available OD-data per sector is therefore a valuable source, but it should be clear that it is based on unclear assumptions and can be amenable to mistakes.

The demographic zones on which the estimations of demand in this study are based, the sectors, are too large for analysis in a PSS and should therefore be disaggregated in *Traffic Analysis Zones* (TAZ's). The trip information from these zones should ideally be disaggregated based on land use or built-up area maps, but can also be based on the assumption of homogeneous distribution over the zone. This is further explained in section 4.3.2.

The *trip assignment* to the network is done in the software package *Flowmap*, which was designed by the faculty of Geosciences of the University of Utrecht (Faculty of Geosciences University of Utrecht, 2012) . The software can be used to assign trips to a network and make this available for further spatial analysis. It is a free software package, which is convenient for this research and for the further use of this study in Rwanda. Although the software only provides a coarse overview of assigned trips, it is good enough to give a first impression to policy makers, without having to pay for expensive traffic simulation models.

The assignment is done using the all-or-nothing assignment method. This is done to ease calculation in an environment that is aimed at spatial information and because of the limitations of Flowmap. It can however be assumed that people do not have much choice in their travel behaviour and that they choose the most optimal route, which is often the shortest. This will mean that they will wait at bus stops and take the first bus that goes in their direction until they reach their destination, possibly by including some transfers to other routes. As it is never sure when the next bus will arrive, it is assumed that all buses going in the right direction are a potential means of transport for people waiting at a busstop. This is of course a very generalized situation, but detailed enough for the scope of this study.

2.3.1.2 Dimensions of demand

The passenger demand as described above is available in a spatial dimension disaggregated from sectors to TAZ's and assigned to the network (which will be elaborated on later). In a temporal dimension, it is available for the morning and afternoon peak hour and for the busiest period in the off-peak period around noon. These three peak periods are clear from Figure 6, which represents all traffic within the scale of the survey. It might be possible that the afternoon peak hour actually takes place after the survey period, but there is no data for this period.

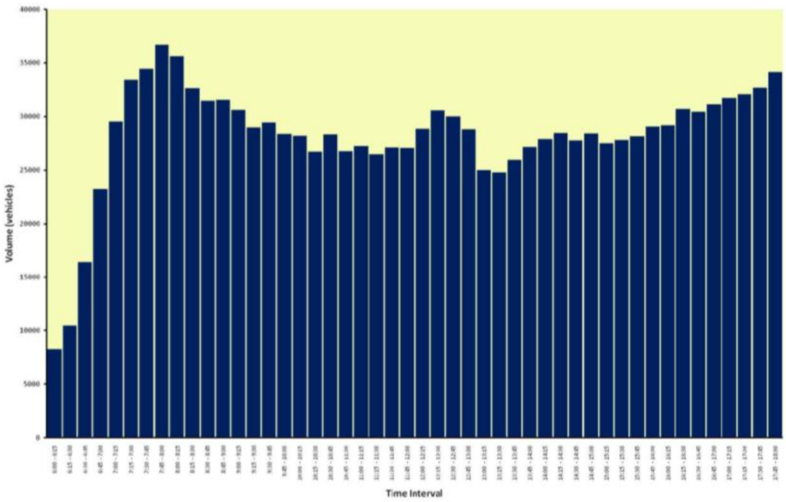

Figure 6: Total traffic volumes on all roads in Kigali, showing the three peak periods (SSI Engineers, 2011)

The calculations are based on an average weekday, and the underlying information is collected on multiple different weekdays. (SSI Engineers, 2011)

2.3.1.3 Demand growth

If more data had been available, the demand per zone could have been generated by estimating *potential demand*, which can be calculated based on population, population density and land use situation of a zone. This information links the generation and distribution of trips to residences and jobs, which makes it easy to extrapolate growth in trips using growth factors (Ortúzar & Willumsen, 2001).

The demand for public transport is likely to change over the years, due to changing population densities or the development or changes in land use of certain areas. This will have effects on the production and attraction values of these areas, and will thus increase the trip generation. The change in trip distribution is harder to estimate, as trip distribution in this study is based on observed trips. It is therefore assumed in this study that growth of all OD-pairs is relative to the total growth of production or attraction in the zone. This makes it possible to use the general growth-factor method for trip growth, adapted from Ortúzar & Willumsen (2001):

$$\boldsymbol{T_{ij} = F_{(ij)} t_{ij}} \tag{2.1}$$

where:

T_{ij} =	The future trips with origin *i* and destination *j*
$F_{(ij)}$ =	The growth factor (for all trips or per OD-pair or zone)
t_i =	The current trips with origin *i* and destination *j*

This method of course limits the opportunities to introduce new zones, that can be served by the system when it is extended. To be able to account for these zones, new observations should be done to recalibrate the OD-matrices, or the generation and distribution of these zones should be made relative to other zones or for example relative to travel distance. Because the exact trip generation and distribution model is not available for use, new zones are not possible to produce in this research.

2.3.2 Public transport supply

A bus public transport system consists of a few basic operating elements. These are basically the physical network, which consists of multiple routes that are connected at stops, and the vehicles that operate on these routes. The vehicles are in their turn operated by drivers and fare collectors, who together with maintenance and security staff form the employment force of the public transport system. The operation of the system can be described in terms of its temporal characteristics and physical capacity.

2.3.2.1 Bus routes and stops

The bus network in a city consists of multiple routes, which overlap on some streets (links). In some cities, parts of bus routes run on dedicated roads, to allow for priority at links and junctions. This is however not the case in Kigali, where bus routes share street space with other vehicles in mixed traffic. The bus stops begin and end at terminals, which are often the furthest bus stops in the suburbs of a city or transfer hubs near the city centre, where a lot of buses connect. On their route, buses stop at bus stops to allow passengers to board, alight and transfer to other buses.

2.3.2.2 Vehicles

The vehicles that operate the bus network can be of multiple types. In Kigali, these are minibuses with 17 seats, coasters with 28 seats and large buses with 60 seats available.

The buses in Kigali do not run on a timetable or schedule, but try to operate at full capacity of each vehicle. For this study, we assume that this will ideally lead to a homogeneous distribution of vehicles on the network, or that the government will do its best to regulate this homogeneous distribution through the introduction of maximum waiting times at stops and terminals. This generalization makes it possible to calculate average operation indicators and will also be a focus of rationalization policies.

The buses in the network are assumed to operate at an average speed that can be varied to adjust for congestion. This average speed is assigned to all vehicle types.

2.3.2.3 Vehicle headway

The headway between vehicles, which can be defined as the time interval between the moments two successive buses in the same direction pass a fixed point, determines the movement of buses on routes (Vuchic, 2005).

Passengers are usually interested in short headways, as the headway of vehicles ideally determines their maximum waiting time when the system is not overcrowded. The average waiting time is therefore defined as half the average headway, assuming homogeneous arrival of passengers at the stop. In the rest of this research, we will look at the headways to represent a measure of waiting time. (Vuchic, 2005) Operators, on the other hand, are interested in long headways, as this will increase the probability of operating near capacity (Ceder, 2007). For every bus route, a balance must be found between these two conflicting stakes.

The headway is determined in this study based on the total length of a route, the maximum waiting times at bus stops and terminals and the average vehicle speed, which together form the cycle time of a route. This cycle time can be divided by the number of vehicles to find the (average) route headway, which is further explained in section 4.4.

2.3.2.4 Capacity and load factor

The capacity of a public transport route is the maximum number of people that can be moved in a certain amount of time. The hour capacity of a route is limited by the capacity of the individual vehicles and the amount of vehicles that passes a certain point per hour. The latter is related directly to the average vehicle headway on that route (Vuchic, 2005)

In this study, capacity is calculated both per route and per link, as some links are served by multiple bus routes. The capacity per link, which is also the capacity per bus stop on that link, can be used to determine the capacity utilization coefficient or load factor of that link, which is defined as the amount of persons transported along the link divided by the link capacity. This factor can provide planners with the required information to determine whether the capacity of all public transport routes is sufficient. (Vuchic, 2005)

The load factor per individual vehicle can only be defined when detailed information is available of the total people boarding and alighting per stop per vehicle or route. As this information is not available and calculation would rely only on assumptions, this is not further elaborated on in this study. It is therefore not possible to look at the total load factor of individual vehicles and routes, but only at the factor of links.

2.3.3 Evaluation of public transport systems

A PSS evaluates the effects of policies on predefined evaluation indicators. The definition of these indicators is provided in this section, while the exact construction is described later.

The stakeholders influenced by policies in the public transport sector can be classified into three main categories (Vuchic, 2005):

- Passengers/users
- Operators
- The community/the government

Each stakeholder has different preferences and definitions when it comes to adequacy of the system. These differences will be elaborated on in this section. The final selection of indicators that will be implemented in the PSS will be presented in section 4.4.1.

2.3.3.1 Passengers

Passengers, as users of the public transport system, are often the least well understood in the planning process, because operators and the government are usually involved more closely in the process. Most general public transport evaluation indicators are often aimed at the performance of operators, like the operating expenses, revenues per passenger or vehicle kilometre or the total amount of jobs in an accessible area (Eboli & Mazzulla, 2011). The indicators describing system adequacy in this PSS do not look at these figures, but primarily reflect the direct effects on passengers.

As Gomide, Leite & Rebelo (2005) describe, the supply for public transport is often deficient for low-income groups. In a revealed preference research done under 934 respondents by SSI Engineers in Kigali, 51% of respondents belong to the lowest income class (below 100.000 RWF, around €130,- per month). From this group, 49% of people use public transport as their main transport mode (SSI Engineers, 2011). As the low-income group forms a large part of the population in Kigali and the public transport users, they should also be the main focus of the public transport system in the city.

Inadequacy of the public transport system might shift the interest of passengers away from travelling with public transport, towards using private alternatives. A lot of the public transport passengers in Kigali are however captives, who do not have viable alternatives for public transport besides walking. This evaluation therefore does not focus on the effects of operation on demand shift, but mainly on the quality that is offered to passengers, which also could be a focus for planning departments. Because of the reasons above, there is no direct financial or demand-related incentive for improving this quality and adequacy, but the communal wish to offer a good public transport can still be the main focus of policy makers.

Gomide, Leite & Rebelo (2005) have developed a public transport evaluation index, in which they describe the adequacy of public transport based on four important attributes of the system:

- **Affordability** is the extent to which a user can afford the cost of a journey. This is closely related to both the fares charged and the income of the user. It might be measured as the user's monthly spending on public transport or, more complicated, as an opportunity cost where the indicator measures the amount of goods that the user refrains from buying to be able to afford travel expenses. Although often neglected by policy makers, this is an important indicator for the low-income population groups, as the inability to afford transport could lead to fewer opportunities to reach work or schools (Olvera, Plat, & Pochet, 2008).
- **Availability** concerns the route possibilities and timings of services, especially the pre-transport, waiting and travel times. They have to meet the needs of the user and must be reliable. This attribute therefore has to do with timetables and delays, but also with the availability of services on irregular moments.
- **Accessibility** is the ease with which passengers can use the system. This is most easily measured by the distance users have to travel to the nearest bus stop, but can also include access to information and access to the system for minority groups, like elderly or disabled

people. Barriers for accessibility might include both physical (highways, buildings, waterways) and social barriers (crime, safety).

- **Acceptability** is the quality of service compared to user's expectations. These expectations differ from place to place, but are usually aimed at the condition of vehicles, the behaviour of drivers and the level of comfort and security. This attribute is highly subjective and is therefore difficult to measure in a rational indicator. It is however closely related to the level of service, because this directly affects comfort and discomfort like overcrowding.

These four attributes are also mentioned by other sources that describe the connection between (public) transport and social exclusion. The attributes are described by Titheridge (2004) as the "four ways in which people can be socially excluded by transport". In the same way however, these indicators could also measure the inclusion of these people, when positive scores are found on the attributes.

The method of Gomide, Leite, & Rebelo is especially applicable in developing countries with a high share of low-income users, because it incorporates the relative and stated needs of users, instead of standard evaluation measurements that are only interesting to operators (Gomide, Leite, & Rebelo, 2005; Lomme, 2008). This provides chances to judge the social exclusion of areas that are poorly served by public transport.

The attributes described by Gomide, Leite & Rebelo can be measured with a lot of different indicators, depending on the requirements of the PSS. For the situation in Kigali, as described earlier, a few problems could be leading in possible policy scenarios. These problems are placed under one of the four attributes in Table 1, a method that is also used by Gomide, Leite & Rebelo to find suitable indicators for a specific situation. A possible indicator has been linked to most of these problems. To some problems, no clear PSS indicator can be linked. This usually indicates that the type of problem is not spatially related and should be addressed with regulatory measures.

There is also some criticism on the methods of Gomide, Leite & Rebelo in other literature. Gómez-Lobo (2011) for example notes that especially for affordability, the simple calculation method of Gomide, Leite & Rebelo is rather arbitrary. It defines affordability as the ratio between fare price and household income, while the transportation needs of a household may in reality depend on other factors, for example on the "normal" modal split in a certain income class. This is also the case with public transport in Kigali, but as we try to measure only the ability to pay for public transport, the simple method of Gomide, Leite & Rebelo will be adequate enough.

All four attributes should be used to come to a complete system evaluation, but a selection of a few attributes can also be made to assess certain parts of the public transport system. This selection should be made as much as possible by the end-user of the PSS, who should be able to select all indicators he requires.

Attributes	Problems	Possible indicators
Affordability	• People in low income areas might not be able afford higher public transport fares • Fare differences in informal and formal public transport	• Average income vs. price of fare (expenditure on transport) • Willingness-to-pay for shift to formal public transport
Availability	• Few routes to remote locations • Irregular headways/long waiting times • Long travel times • Long delays possible in off-peak hours • Too low capacity in peak hours • Too low capacity per vehicle	• Availability of public transport within certain amount of time • Regularity of headways and average headway • Travel times towards areas of interest • Vehicle and route capacity
Accessibility	• Large distances to bus stops in remote locations • No timetable operation	• Walking distance following the network towards bus stops or service area of bus stops • Service in situations with randomly distributed vs. scheduled buses
Acceptability	• Crowded vehicles • Bad maintenance of vehicles • Willingness-to-pay for more comfort or reliability is unsure	• Demand satisfaction ratio/level of service • Experienced comfort • Age of vehicles • Expectations of users for comfort and maintenance

Table 1: Public transport evaluation attributes, problems and indicators

The final effort made by Gomide, Leite & Rebelo is in developing a synthetic index, which normalizes all scores of the individual indicators and brings them together in a single index score. This score is called synthetic, because it combines the relative scoring of indicators and does not have any direct meaning anymore. The construction of such an index is not the final goal of the PSS created in this research, as it tries to provide users with a set of indicators from which they can choose themselves. There is however also room for this kind of indices in a PSS, to give users a first impression of areas of interest for reviewing. A single index, based on the four mentioned passenger quality attributes, is therefore presented in the PSS to show the possibilities of this feature.

2.3.3.2 Operators

The public transport supply is provided by transit operators, who can also benefit from the results presented in the PSS. Next to their primary target, to reach profit by moving passengers, they are interested in some indicators that are also important for the passengers. These are for example *good area coverage* (e.g. walking distance along the network towards bus stops) and *route capacity* (e.g. percentage of buses full), which are factors operators would want to optimize for to maximize profit (Vuchic, 2005). Other operator requirements and concerns, like reliability, flexibility, safety and air or noise pollution (Vuchic, 2005) are less spatially connected and more focussed on operation, which makes them harder to model in a PSS.

The most important requirement for operators, especially in an informal public transport system, is however often the total cost coverage of the operation. While the constant costs of policies, for example the *capital costs of introducing new bus stops or route expansions*, can be taken into account, the total operation costs of a route should be calculated parallel to the PSS evaluation.

The *efficient distribution of vehicles* on the network and the *total number of employees* required to operate these vehicles are interesting indicators to optimize for a public transport operator. As these indicators are also interesting for the government, they are good candidates for development of PSS indicators.

2.3.3.3 Government/community

The requirements of the general community, often represented by the government, largely overlap with the requirements of passengers and transit operators. Policy makers in this user group are one of the user types of the PSS that will be developed in this study. They try to create a transit system that supports the needs of as many other users as possible. According to Schiefelbusch & Dienel (2009), the government representing the community can be as the actual customer of public transport seen alongside the passengers, as they often contribute to the financing of the system and value the continuous operation.

The government is concerned with the well being of the inhabitants of the city, which makes them value the requirements of passengers. They however do not look at individual availability and accessibility, but rather at the *total passenger attraction* and *social exclusion* of some areas. They further value the effects of the transit system on *air and noise pollution and traffic congestion*. These elements should however be modelled in detail in microscopic transport models, and cannot be taken into account in a PSS easily.

A major concern of the government is the total system cost of the transit system. Much like the cost coverage of operators, this figure is hard to calculate only based on spatial elements. The *capital costs* should however be an indicator in the PSS, because they limit the scope of potential policy scenarios. Users of the PSS need to be able to define a *budget*, which limits the options for development

Another valuable indicator for the government is the total *vehicle park size*. Governmental policies to shift services from minibuses towards larger vehicles can be monitored with an indicator in the PSS, which allows for optimization of the vehicle park towards a required combination of vehicle types. As the government values the conservation of employment, the *total employment* in the sector is a valuable indicator.

Field study

3 Field study

The practical research done in this thesis consisted of a field study in Rwanda and a PSS development study done at ITC in the Netherlands. During the field study, various datasets were collected from stakeholders in Rwanda and discussions and interviews were conducted with potential users of the PSS. This has resulted in a clear understanding of the problems in the field and an overview of the opportunities for this research. The experiences from the field study, which took place in the first part of the research period, have been important in the final definition of the research objectives and requirements of all stakeholders.

It was decided not to do a quantitative primary data collection in Rwanda. The field study had a highly unclear outline, as the research problems had to be partly defined during the field study. This had to do with the communication prior to the field study and the difficulties with defining what could be expected in Rwanda. Furthermore there were practical issues concerning the available time in Rwanda and the availability of assistance and funds. It was agreed that collecting existing datasets, supplemented with personal observations and interviews with stakeholders, would give a clear overview of the current planning situation and that it would be good to start the rationalization discussion from there.

Chapter outline

This chapter will describe the various insights that were gained during the field study and will critically assess the data that was gathered. This is used as an exploration of the required properties of the PSS. The first section describes the outline of the field study and points out to the personal observations in the appendix. Section 3.2 mentions the interviews that were done as primary data collection, while section 3.3 focuses on the quality of the secondary datasets that were retrieved. The summary and conclusion of the field work at the end of this chapter describes the relation of the field study with the theoretical framework in Chapter 2 and the development of the PSS in Chapter 4.

3.1 Field study description

3.1.1 Internship at MININFRA

The field study took place in April 2012, and was organized in collaboration with the Rwanda Ministry of Infrastructure (MININFRA). They have provided the means for doing research in Rwanda, by providing office space, contact addresses and practical help. From the office of International Transport Expert Mahabubul Bari, visits were made to the Rwanda Utilities Regulation Agency (RURA), the Kigali City Council (KCC) departments of Transport and Land Use Planning and the National Institute for Statistics Rwanda (NISR), to do interviews and to collect existing datasets.

Other relevant data was gathered through conversations via e-mail and real-life meetings with South African transport consultant SSI Engineers. They presented their draft Public Transport Master Plan during the field study, and their report and raw and processed data were used in this research.

3.1.2 Personal observations

During the field study, some personal observations of the public transport system and the transport system in general were collected. These were used to make a correct interpretation of the quantitative data and to be able to make qualitative recommendations in this thesis.

The public transport system was briefly compared to the system in Kampala (Uganda), to be able to define the up- and downsides of the system in Kigali compared to another city in the region. The main observation was that although the city of Kigali seems to be much stricter in urban development planning, the relative chaos of the Kampala public transport system could represent the system of Kigali in a few years' time, if no rationalization actions are undertaken. This comparison was only based on field observation, not on conversation with planners or existing datasets. It was therefore not used as an important source in this report, but only as a reference for the description of the research context.

A summary of the personal observations during the field study is presented in Appendix 1.

3.2 Primary data collection

To get a clear overview of the requirements for rationalization and planning support in Rwanda, interviews and discussions with local experts and planners were undertaken. This has led to important insights in the practice of public transport planning in Rwanda, which can be used to justify the importance of the rest of this research.

3.2.1 Interviews with local experts

During the field study, contacts were established with local experts in the Ministry of Infrastructure (MININFRA), the Kigali City Council (KCC) and the Rwanda Utilities Regulatory Agency (RURA). The complete worked up interviews are in Appendix 2 and 3 and the most important results and interpretations are shown in this section. The interviews in Appendix 2 (Rurangwa, 2012) and 3 (Muvunyi, 2012) are also referred to in the bibliography of this report, to be able to consolidate statements about the planning practice in Rwanda in other sections.

It was chosen not to undertake an interview with the Rwanda Transport Development Agency (RTDA), as this agency mainly focuses on the construction of roads and is not directly involved in the public transport planning process. They do however seem to have a role in the decision-making, as they are mentioned by MININFRA, KCC and RURA as present in decision-making meetings. It is assumed in this study that the description of RTDA provided by these authorities is correct and that they are only involved in the process when it comes to road construction issues.

During the interviews and in the rest of the field visit, it was hard to detect the attitude of the various experts towards introduction of a PSS in the planning process. This mainly had to do with the unfamiliarity with the concept of the interviewees at the start of this research. The probable attitude towards the use of a PSS is therefore assumed based on the statements made by the interviewees.

3.2.1.1 Discussion Mahabubul Bari, International Transport Expert MININFRA

Dr. Mahabubul Bari is a transport expert who has studied and worked in the United Kingdom before coming to Rwanda. He has had several occupations at RTDA and MININFRA and is currently advisor to the Minister of Infrastructure and Minister of State in charge of Transport at MININFRA. There has not been an elaborate interview with Bari, but several discussions were undertaken with him in his role as daily supervisor during the internship. The statements made below are the main new observations and interpretations that appeared from these discussions.

Extensive transport planning is still very fresh in Rwanda and that large development projects have not been undertaken much. The public transport system and road network are the ministry's main concern, but there are a few bigger dreams for large infrastructure projects, including a new airport, railway projects and BRT lines. These big projects however do not seem to be feasible in the short term, as they not only face financial and planning problems, but also seem to lack potential users.

There is no single public transport agency in Rwanda, which puts the weight of integrating all efforts for public transport planning onto MININFRA. The ministry tries to control the planning process by connecting all stakeholders, but each stakeholder appears to be very secretive when it comes to the rationale behind decisions and the provision of data. This is one of the major reasons why creating a public transport agency to rationalize the planning process is a major focus of interest of Bari and MININFRA.

The Rwandan culture of bureaucracy and formality, which is held in place by the tendency to avoid any form of corruption, tends to slow down development and efficient policy making. Comprehensive collection and joining of data with the goal of streamlining decision making would therefore speed up the development process of the transport sector.

The importance of collecting and combining datasets is acknowledged by Bari. Any effort in structuring the available data that can be used for public transport planning is therefore useful for his work at MININFRA.

3.2.1.2 Interview Jean Claude Rurangwa, Transport Expert KCC

Jean Claude Rurangwa is the main transport expert at the Kigali City Council Transport Department. He is responsible for the planning and management of the public transport system, but his responsibilities also range out to traffic lighting and road construction. A semi-structured interview was undertaken with him to determine the current practice of planning for public transport. This interview can be found in Appendix 2 and is referred to as (Rurangwa, 2012). The most important results of this interview are displayed below, followed by a brief interpretation.

Results

There are three main types of buses in Kigali City, which are the minibuses, coasters and large buses. The coasters and large buses are rather new, as they have mainly entered the system after 2008. The current policy, according to Rurangwa, is to phase out minibuses by not issuing new licenses for these vehicles and replacing them with larger vehicles.

The KCC Transport Department is mainly focussing on facilitating the bus system, by investigating the introduction of bypass lanes for buses at congested parts of the network and working on the physical infrastructure of bus stops. The planning of these parts of the system is mainly based on requests by the community for better and more bus stops in some areas. Information provision to travellers is also a main concern in the public transport system, as this is currently not available. The Transport Department is working on providing this with the introduction of new bus shelters.

Most physical projects are initiated by the Transport Department in collaboration with other stakeholders, which happens in extensive stakeholder meetings. The actual planning and construction however are often put out to third parties in a tender. This causes delays in the planning and may reduce the coherence in the planning process.

New bus routes are currently planned in concept by the Transport Department (Rwanda Ministry of Infrastructure, 2012), but according to Rurangwa these plans are not feasible for the short term, because of the lack of operating vehicles in the current network. These statements are however not based on clear data, because the amount of vehicles on each route is not known in the Transport Department and there is no known estimation of trip data.

Time delay is the most important shortcoming of the current system, according to Rurangwa. The lack of a timetable operation and the waiting of vehicles at stops make the service unreliable. This delay is further increased by delays in congestion and long pre-transport distances, which makes the bus transport less attractive than motorized private transport and motor-taxis.

Interpretation

It is clear that the KCC Transport Department tries to make the best out of the public transport system in Kigali City, but that they do not have the proper means for this. The department has to focus on all transport features in the city, reducing the focus on public transport. Furthermore, the department does not have extensive information about the quality and operation of the system and does not have full regulatory power, as this is shared with RURA and RTDA. KCC is therefore not only served by a PSS that provides them with a clear data structure, but also by the open planning meetings a PSS allows. In these meetings, KCC can work together more properly with RURA and the other stakeholders to create an integrated public transport policy.

3.2.1.3 Interview Deogratias Muvunyi, Director of the Road Transport Unit RURA

Deogratias Muvunyi is director of the Road Transport Unit in the Transport Department of RURA. This is the organization that is concerned with providing licences for road transport, which primarily focuses on public transport. A semi-structured interview was undertaken with him to determine the role of RURA in the public transport system and the policies it follows. This interview can be found in Appendix 3 and is referred to as (Muvunyi, 2012). The most important results of this interview are displayed below, followed by a brief interpretation.

Results

Muvunyi describes RURA as the “referee” in the system, which creates regulations and makes sure they are followed by all operators and other stakeholders. They are therefore not too closely connected at the planners and policy makers at MININFRA and KCC, because this would endanger their neutral status. According to Muvunyi, they are however cooperating as much as possible with other stakeholders, especially in the policy making stakeholder meetings in which they seem to have an important voice.

The issuing of licenses by RURA does not happen according to quota. Every private operator, cooperative or public transport company can apply for a license on any route if they apply to all regulations set by RURA. There is no cooperation on limiting the amount of vehicles per route or area, as it is assumed that this will be effectively regulated by the market. There are however no figures proving this, as RURA does not collect trip data and does not keep an archive listing all vehicles on a route.

RURA has recently introduced a policy that limits new entrants with minibuses that want to start operating the Kigali bus system. Current operators with minibuses can however still apply for extension of their contract. The phasing out of minibuses will therefore probably take a few more years in the current system, but this accepted as a transition period by RURA.

RURA is currently advising and helping individual operators to form and join cooperatives, which will have more bargaining power and economies of scale. After the phasing out of small individual operators, a new licensing system will be introduced to these larger companies and cooperatives, including tendering and concessions per route or area. This would shift the responsibility of offering enough supply to serve demand from the government to the operators themselves.

Next to licensing operators to serve each route, RURA is responsible for setting the mandatory fare prices for all routes. This fare price is based on a cost price estimation by RURA, which is constructed into a fare price per kilometre during stakeholder meetings. These meetings include representatives of the operators and consumer protection associations, which are present to bargain for their own stake. The cost price is based on fixed costs like vehicle depreciation, maintenance and insurance and on variable costs like the estimated travel time and distance per vehicle. This is however based on aggregated travel times and the average price of a coaster bus, and is therefore only an approximation of the real cost price. The regulation of all operators keeping to the mandatory fare prices is done by the operators themselves, which can report irregularities to RURA and the traffic police.

Interpretation

The main tasks of RURA, the issuing of licenses and the estimation of fare prices, would be much more effective if they were done in closer cooperation with other stakeholders. The enabling of data sharing and scenario bases planning in a PSS would therefore aid this agency in its tasks and enable clear cooperation, without endangering their neutral position.

3.2.2 Meetings with planners

Two meetings involving external land use and transport planners were held during the time of the field study. In one of these meetings, consultancy company SSI Engineers presented their draft public transport master plan to a group of decision-makers, including the minister of State in charge of Infrastructure. The other meeting took place later that week, between consultants of SSI Engineers and the SURBANA Urban Planning Group. The latter have been hired to develop a land use master plan for Kigali City.

During the meetings with these consultancy companies, it became clear that Rwandan planners are dependent on external expert input for the planning of their public transport, but that they are not always content with the results. The use of PSS, in which also external parties could cooperate, would reduce their dependence and make the planning process better controllable. It would also reduce redundancy in data collection and display all available data to guide field work planning by consultants.

3.2.2.1 Presentation SSI Engineers at MININFRA

In the third week of the field study, two consultants of SSI Engineers, a South African transport consultancy company connected to the DHV Group, presented their draft public transport master plan for Kigali City. This presentation included an analysis of the current demand for public transport and an outline of short and long term plans for the public transport system. This mainly included physical changes to the road, favouring a reliable bus system with dedicated bus lanes. Other recommendations included feeder systems by minibuses and motor-taxis.

The presented plans were overheard by a group that consisted of most major decision-makers in the public transport planning process, and was therefore a good model for the setting in which our PSS should work. Most stakeholders were actively joining the discussion about the plans and the discussion was dominated by questions about the assumptions made by SSI. It was clear that all representatives of stakeholders had their own vision on the restructuring of the public transport system, based on various different datasets or experiences. The plans made by SSI were not accepted in the end of the meeting, and a new draft version was requested from the consultants. This mainly had to do with the unclear assumptions of the consultants and the unexpected rigorous approach of laying out completely new bus lanes.

From this meeting, it was clear that PSS would have been valuable in this kind of meetings with policy- and decision-makers. It would have both structured the presentation of SSI's plans to all stakeholders and allowed these stakeholders to come up with their own scenarios for comparison.

After the presentation, personal conversation with the SSI consultants led to the conclusion that the master plan developed by SSI did not conflict with the scope of this thesis, as it mainly focused on providing one possible solution, instead of developing an interactive planning structure. I could however be used as one of the possible scenarios to be compared in the PSS. The master plan itself was tendered by the Ministry of Infrastructure, but would only be definitive after extensive collaborative evaluation with multiple stakeholders, in which a PSS would be helpful.

The primary data collection done by SSI Engineers however already proves to be very valuable for the construction of a draft PSS, as it provides a clear overview of all trips made in Kigali City on an average week day, with all modalities. Both the raw data and the trip matrices were acquired from SSI, and their properties are described in a later section.

3.2.2.2 Discussion with SSI Engineers and SURBANA Urban Planning Group

In a meeting with SSI Engineers and Singaporean SURBANA Urban Planning Group, which took place at the Ministry of Infrastructure, the two consultancy companies developing master plans for Kigali City were urged to cooperate in their planning work. Both companies laid out their plans, data collection principles and growth estimations, and it turned out that a lot of important interactions between land use and transport did not match in the two plans. There were a lot of conflicting assumptions, which made discussion between the planners difficult.

This difficult discussion between different disciplines further displayed the role that a good PSS can have in the planning landscape. By managing datasets, visualizing data and allowing interactive manipulation, even meetings between expert planners can be structured, especially when they each have their specific specialities.

3.3 Available datasets

As the focus of this research is to use existing datasets to structure the public transport planning process, making an inventory and collection of existing data was an important goal of the field visit. The collected data is ordered in four groups:

- Public transport demand data
- Public transport supply data
- Land use and demographic characteristics
- Other data, such as fare pricing data and preference surveys

In this section, all collected datasets will be shortly described and judged for their value.

3.3.1 Public transport demand

To estimate the demand for public transport, we use available demand data as much as possible. The major data we use are the OD-matrices generated by SSI Engineers. These matrices, which are organized by sector, can be disaggregated into TAZ's using population data per sector and cell.

3.3.1.1 Demand analysis SSI Engineers

Consultancy company SSI Engineers (SSI), which was mentioned in earlier sections, is currently studying the public transport system in Kigali City. This study was commissioned by the Ministry of Infrastructure and has been in progress since a tender 2009. The main goals of this study are to do gather data about the demand for public transport in Kigali City and use this to develop a public transport master plan. This master plan should contain demand forecasts and propose an extensive plan for changes in the public transport system up to 2028, including financial, legal and management effects. A microsimulation model and all dataset used in GIS and transport models belong to the final outputs of the study (Rwanda Ministry of Infrastructure, 2009). The study was not finished at the time of this research, but some intermediate results were available as inputs of this study.

SSI conducted a traffic survey, in which they observed the link intensity and vehicle occupancy on various locations throughout the city, and conducted interviews with travellers on the roadside and at taxi ranks. Raw data is available from all these surveys, but the data is very cluttered and unstructured.

The surveys resulted in an overview of the traffic in Kigali on an average weekday between 06:00 and 18:00. Three peak hours were identified and were further investigated. These peak hours were defined in the early morning, during the mid-day lunch hours and in the late afternoon. It was found that during the off-peak periods only a slight drop in traffic volume occurs (SSI Engineers, 2011).

From the traffic counts and the interviews, in which people were asked for their origin and destination zones, OD-matrices on sector level were defined for the three peak hours. These OD-matrices were used in this report as the source for the observed demand. It should however be noted that the data that these matrices were based on data that was collected during research in a single week, without taking into account weekend days, differentiation between weekdays and between seasons. It also relies on categorization of uncategorized open questions in the surveys (assignment of origin and destination sectors to locations mentioned by people). The demand for public transport could furthermore be somewhat biased, because the system's supply is already based on demand, as most buses will only leave the terminal if they are full. Occupancies and volumes of vehicles will therefore automatically be different between periods of the day, which has effects on the real demand.

Although the produced OD matrices may therefore not completely reflect the real demand, they are used nevertheless to represent demand in this study, as they cannot be reproduced easily without extra data collection and extensive modelling. The concept of rationalization with the available data urges for the use of these existing datasets, as they are expensive to recollect and therefore important to use in as many ways as possible.

3.3.1.2 Population data National Institute of Statistics of Rwanda

The National Institute of Statistics of Rwanda (NISR) was approached to provide recent socio-economic information about Kigali City. The last Population and Housing Census already originates from 2002, after which the population of Rwanda and Kigali City has increased significantly. The most recent other report providing population data on sector level is created in 2008 (National Institute of Statistics of Rwanda, 2008), which is also already quite old. These are however the figures on which current policies are based. A more recent research was published as the third Integrated Household Living Conditions survey (EICV3, abbreviated from the French translation) in 2012, but these results were only available on district level (National Institute of Statistics of Rwanda, 2012). In this thesis we will therefore work with the data from 2008.

3.3.2 Public transport supply

The public transport supply system consists of the bus routes and the vehicles operating these routes. At the start of this study, there was no single source who owned a consistent supply data set, so data from different sources had to be combined to get a clear overview.

3.3.2.1 Supply research David Niyonsenga

David Niyonsenga, a Rwandese MSc. student who conducted his thesis research at ITC, has also studied the Kigali City public transport system (Niyonsenga, 2012). For this research, he has conducted a primary data collection, to record all bus routes and stops in Kigali City and to survey the vehicle volume and occupation level on all routes. The mapping of routes and stops was done using a GPS device, which has resulted in very accurate GIS data that are more detailed than the data currently used by the Rwandan planning departments. These GIS data are therefore used in this study to represent the current public transport network.

The recorded vehicle numbers are however not very accurate, as their collection process was biased in many ways. The routes were observed on different weekdays, sometimes with differing observing hours and they were clearly only a snapshot of reality. As there is no timetable operation in Kigali, the headways and travel times of vehicles vary a lot and the data are not significant enough to find patterns in this behaviour. These data were used by Niyonsenga to make the recommendation to further improve the system (Niyonsenga, 2012), but the dataset is not reliable enough to make good recommendations on the direction of these improvement policies.

3.3.2.2 Licensing information Rwanda Utilities Regulation Authority (RURA)

The Rwanda Utilities Regulation Authority is in charge of issuing licenses to bus operators. They hold the contracts of all bus operators in digitized paper contracts that are not fit for reviewing as a dataset. These contracts were imported into Microsoft Excel in this study, to be able to use them as a dataset containing all licenced busses per route, including their size, age and license plate information. Because of the manual and unstructured way of issuing contracts, a classification had to be made to link all buses to all routes. The results of this classification can be used to assign buses to all routes in the base scenario.

3.3.2.3 Supply research SSI Engineers

SSI Engineers have developed their own representation of the public transport network, which is however not based on digitization of physical bus routes but on the traffic surveys they have conducted. The dataset is therefore less complete than the one collected by Niyonsenga, which makes it less suitable for use in this study.

3.3.2.4 Supply research Ministry of Infrastructure (MININFRA)

The Ministry of Infrastructure (MININFRA), in cooperation with the KCC Transport Department, has developed an overview of the public transport network including possible new routes in their public transport master plan (Rwanda Ministry of Infrastructure, 2012). The development of these new routes is however based on old traffic surveys conducted by Japan Engineering Consultants Co., Ltd (Japan Engineering Consultants Co., Ltd., 2004). This report is therefore not up-to-date, but can be used in the construction of scenarios.

3.3.3 Land use and demographic characteristics

During and after the field visit, current land use maps or datasets of Kigali City were not available. Land use maps are under construction by consultancy company SURBANA Urban Planning Group together with the Kigali City Council Department of Urban Planning, but their intermediate results could not be used in this study. This has limited the ability to target the estimation of production and attraction of trips in the city.

From the dataset of Niyonsenga, GIS shapefiles containing the demographic zones in Kigali City, the outline of the build-up area, the height contours and the road network were available. They were collected from governmental institutions in Rwanda and were used as inputs for this study. The road network was not suitable for network analysis due to inaccurate modelling, but this is corrected in this study to be able to use it.

3.3.4 Other data

To be able to create a clear PSS, some other datasets were collected from various sources.

3.3.4.1 Fare pricing manual Rwanda Utilities Regulation Authority (RURA)

RURA keeps a list of the current fare prices that are allowed on each route. These are based on an estimation of the total cost price of public transport per kilometre, including profit margins. The final prices are estimated in stakeholder meetings with planners and policy makers, in which PSS could help to structure the decision-making process. The estimation figures are available for use in the fare pricing manual and can be implemented in the PSS.

3.3.4.2 Preference survey Japan Engineering Consultants (JEC)

In 2004, a public transport study ordered by MININFRA was conducted by Japan Engineering Consultants Co. (Japan Engineering Consultants Co., Ltd., 2004). In this study, a small preference survey was conducted with public transport travellers, in which they could express their preferences for the system. This information can be used to make an estimation of the acceptability level of the current system.

3.3.4.3 Preference study SSI Engineers

During their research, SSI Engineers have conducted a revealed preference survey, in which they asked people for their weekly travel behaviour and their socio-economic details, including their income, education level and mode options. This information can be used to estimate the affordability and acceptability of the system to (potential) users, but also to get a broader view of the use of the public transport system. This dataset has been mentioned earlier as (SSI Engineers, 2011)

3.3.4.4 Aerial photographs GIS department NUR

Recent aerial photographs of the Kigali City area were collected from the GIS department of the National University of Rwanda (NUR), to use as a base layer for the PSS. The clear detail of the photographs makes it easy to navigate through the network and to recognize parts of the city.

3.4 Field study summary and conclusion

The field study has been used to gather as much relevant data and knowledge as possible, to be able to fully understand the research problem and describe the system in more detail. The main findings of the study are summarized here, but the details mentioned are also already used in the final definition of the research rationale and the theoretical framework.

The theory about the need for public transport rationalization (section 2.1.4) and the potential for the use of a PSS in Rwanda (section 2.2.3) are described using the knowledge gained during the field study, while the assessment of the public transport system in section 2.3 already looked ahead using some observations from this chapter. For the structure of this thesis, the theoretical framework was placed first, but it has been constructed in an iterative process between literature research and field study.

The discussion with dr. Bari and the interviews with Mr Rurangwa and Mr Muvunyi have led to insight in the current state of public transport planning. The roles of MININFRA, KCC and RURA have become clear and their requirements for a PSS, although not explicitly mentioned, could be deducted from their statements. The meetings with external planning consultants made the requirements for planning support even more clear, as their practice could both be supported with and integrated by the use of a PSS.

The datasets that were collected are both used for understanding the planning and operation of the system and for the construction of the PSS. The field study therefore bridges the gap between the stated planning challenges, the theory and possible solutions in the field. Only existing datasets were collected, but almost all datasets had to be restructured, remodelled or combined with other data to be able to understand or use them. The work done to gather and combine all datasets therefore also has an extended use after this thesis, as it forms a prototype data warehouse for public transport data.

Because some datasets consist of pure secondary data, without availability of the raw collected data, it is not fully interoperable. This is for example the case for the demand data collected by SSI Engineers and the socio-economic data from NISR. This has its results on the capabilities of making the PSS fully interoperable, which will delimit the scope of the prototype PSS presented in the next chapter.

Prototype development

4 Prototype development

Using the knowledge gathered through the literature research and the field work, the development of a prototype PSS for Kigali is described in this chapter. This prototype is not fully functioning yet, but the main indicators are implemented and the prototype can be evaluated for further development.

Chapter outline

In the first section of this chapter, the intended users of the PSS in Kigali are defined. With this in mind, the design for a PSS for planning and decision-making in the public transport sector is described in the following section. In sections 4.3 and 4.4, the design is constructed into a prototype of the PSS for Kigali, describing the basic content and the development of indicators. The prototype is used to produce rationalization visions in section 4.5, which are used in the rationalization plan in the next chapter.

4.1 Intended users of the PSS

During the field study, several situations were experienced in which a PSS could have been of help, as was mentioned in chapter 3. These situations were mainly the stakeholder meetings that were mentioned several times. Although I was not able to visit such a meeting, it was clear that these meetings would be helped by clear and simple presentation of data.

The more technical departments, which are already used to working with GIS tools and public transport analysis, would also benefit from a good tool that helps them to display their tacit and explicit knowledge to their principals and to communicate their data with other planning institutions.

The third group of potential users of the PSS are the external parties that provide new knowledge to governmental institutions. These are for example the consultancy companies that are hired by one or more of the policy-making institutions to make more detailed designs. These designs can be presented back to their clients in the PSS they are already working with. This both enables consultants and governmental institutions to communicate more clearly and adds information and knowledge to the PSS, which makes it more valuable for future use. Other external parties might be for example the NISR or the Rwanda National Resources Authority (RNRA), which are governmental organizations that are mainly collecting data and knowledge.

The intended users of this PSS are therefore the following, presented in Table 2:

Policy makers	Planners	External parties
MININFRA	KCC Transport Department	Transport consultants
RURA	KCC Land use Department	Land use consultants
KCC	Public transport operators	NISR
Traffic police	RURA regulation officers	RNRA
Representatives of operators		
Representatives of travellers		

Table 2: Intended users of the PSS

Important characteristics of a PSS, which were mentioned in section 2.2.3 and are guiding principles for the development of a prototype PSS, are the following:

- *Help structure and rationalize the public transport planning meetings*
- *Structure, align and warehouse all available data*
- *Clear interface*

On the one hand, the PSS should be able to aid public transport policy makers in their decision-making meetings; on the other hand it should structure available data which could be used in the more technical sessions of planners and external parties. These two objectives should be displayed in a clear interface, which offers transparency and operability for all stakeholders.

The indicators chosen will focus mainly on the goals of policy makers and planners to serve the needs of the public, which are mainly the passengers. To be able to be attractive for all stakeholders, the PSS should however also serve the needs of the operators and be able to address the challenges of the separate institutions. RURA for example should be supported in the challenge of proposing good fare prices and licensing structures, the KCC planning departments should be able to find optimal locations for bus stops and terminals and consultants should be able to implement and present their own designs.

The differentiation between users will also be visible in the use of the system. The policy makers will often only function as end-users, who only operate in the simplest user interface. Planners would want to get a better understanding of assumptions and equations and will sometimes implement new datasets or indicators. External parties are often only interested in the synergy with their own datasets or will try to implement new data into the system. These different ways of operating the PSS are all possible at the same time, but they require the model and its assumptions to be clear and accessible.

4.2 Design of the Planning Support System

The PSS is constructed in CommunityViz, which is originally a land use planning support system. The design of the PSS is created to be in this software and the vocabulary of CommunityViz is therefore used as much as possible.

In Figure 7, the workflow overview of Figure 5 is reconstructed and expanded into a PSS design. The white rectangles represent the general workflow items as in CommunityViz, where the light shaded rectangles show more detail within these items. The circles represent possible user interferences in the interface that affect the workflow. Darker shaded circles show interferences that will mainly be used by experts preparing the PSS or by planners that want to use the PSS more in-depth. The rest of the interface can easily be used by normal users.

The data part is divided in *map data* (which is provided in GIS datasets), *table data* (for data without a clear spatial component) and *basic content*. The latter is merely the basic map interface presented to users, on which other data are presented. The other two data items placed on top of this basic content are the main datasets that are used in scenarios. While new map or table datasets usually have to be prepared by experts to be implemented in the PSS, the basic content should be easily adjustable by non-expert users. These actions mainly consist of enabling different layers or choosing colour palettes for representation.

The assumptions are divided in *static* and *dynamic assumptions*, which is done to extinguish between assumptions that should be adjusted to create various scenarios (the dynamic assumptions) and the ones that represent environmental choices that should not be adjusted too much (the static assumptions). The latter are often long-term parameters like cost level or population growth, which should be agreed upon by users of the system.

Different assumption levels can easily be grouped into scenarios by the user. After the selection of the required indicators, their values are presented in real time to the user. As already mentioned earlier, this can be in the form of "live" maps, charts (with the option of setting alerts on thresholds) and textual reports. The user is free in selecting from the available map overviews and can also select charts and threshold values. The development of new indicators requires more GIS knowledge and therefore often requires the interference of an expert user.

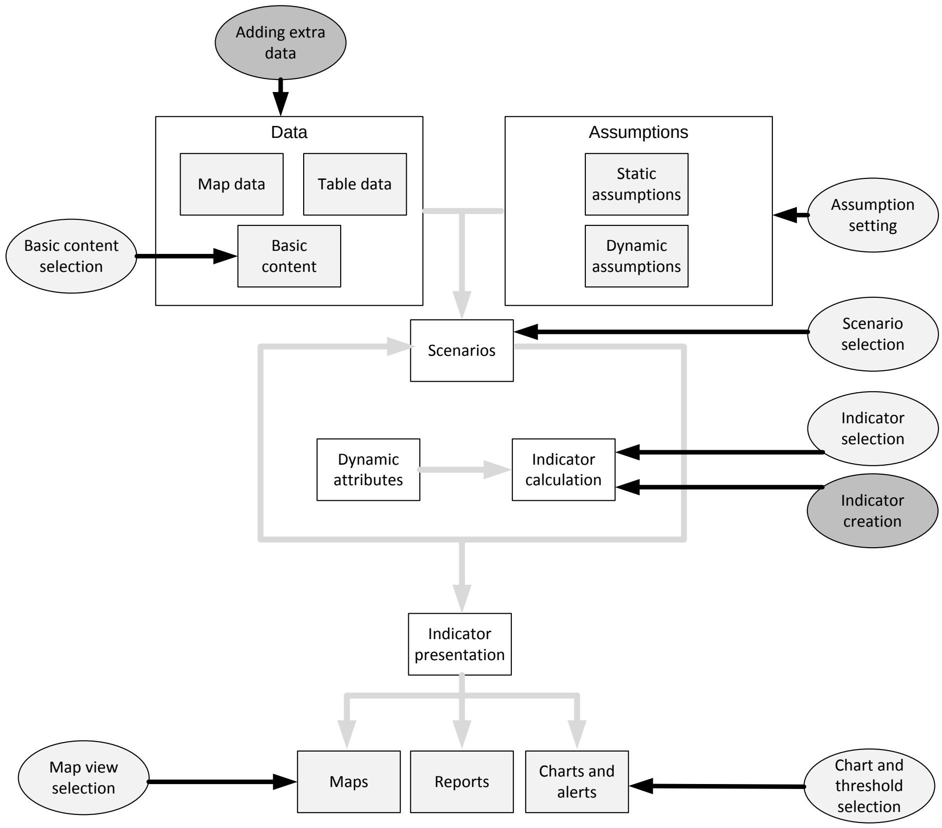

Figure 7: PSS design based on CommunityViz workflow

In the rest of this chapter, several parts of the workflow in Figure 7 will be further elaborated on. The basic content is context and area specific, but is the same for all scenarios described in this research. It will therefore be described separately in the next section, followed by a description of the various implemented indicators. The workflow in Figure 7 will be used in section 4.4.2 to show the choices available to users for each indicator.

4.3 Basic PSS content in CommunityViz

The basic content of the PSS is the standard content a beginning user encounters. It offers a way to navigate through the area and adds reference points on which the results of policies can be presented. It can be fully adjusted to the needs of a user or user group, but consists of standard elements that are described in this section.

4.3.1 Visual and network layers

The basis for a clear and easily interpretable PSS is a data layer that can be understood by all stakeholders. This should include a means of spatial referencing and way-finding, for example aerial photographs or satellite images, and an overview of the basic networks on the ground, such as roads and public transport facilities.

In this prototype, recent aerial photographs of Kigali City are used to give the user the opportunity to navigate through the network. Most users of the system will be familiar with the situation on the ground and the various areas of Kigali City, aerial photographs will help them to combine this tacit knowledge with the explicit knowledge in the model.

Combined with the available height contour dataset, the model can also be presented in CommunityViz Scenario 3D, which enables the user to interactively "fly" over the presented results. This is mainly useful for briefly presenting scenarios in meetings and will help stakeholders to get a clearer overview of scenarios.

The photographs are overlaid with a detailed representation of the public transport links and stops (nodes) digitized by Niyonsenga (2012). The public transport routes are also selectable, with attributes and their route name. The bus stops are linked to each route and have their name and properties attached. The operational information, which is described in a later section, is connected to the bus routes and bus stops by dynamic attributes.

4.3.2 Traffic Analysis Zones (TAZ's)

The available zones that are equipped with population and trip information are the sectors, well known to the users of the PSS as they are the most often reviewed geographic zone in Rwanda. These zones are available with the attributes population, area, population density (derived) and trip production towards each other sector (a full OD-matrix).

Because the sectors are rather large, with often multiple bus stops per sector, they are disaggregated into smaller units, based on the closest bus stop from each point. These units can be used as traffic analysis zones (TAZ's) which are important for trip demand analysis. This disaggregation is done in a few steps:

1. All bus stops are linked to the part of the total study area that is closest to them. This is done by generating Thiessen polygons, which are created by drawing the polygon's borders in such a way that each location in a polygon belongs only to the closed bus stop, as the crow flies.
2. Around each bus stop, a circular buffer zone with a total distance of 2000 meter is drawn. These buffers are an approximation of the total walking distance over the network of 3000 meter, which is selected as the maximum walking distance. This is of course a generalization that reduces reliability, but the network that is available is not suitable for more detailed analysis.
3. The buffers and Thiessen polygons are combined with each other, which creates zones that are the unique catchment area of a bus stop (based on walking distance and the assumption that people always use the closest bus stop).
4. These unique catchment areas are overlaid with the sectors, which creates smaller sub zones in the catchment zones that are attributed with the trip information of sectors. This information is based on the area size of each small sub zone, assuming homogeneous

production and attraction over each sector, but concentrated on the areas served by public transport.

5. The sub-zones are aggregated again to the unique catchment areas per bus stop (TAZ's), trip production and attraction information towards each other TAZ.

This estimation is based on a few assumptions. These are not only the homogeneity of the trip data, but also the assumption that people only use the exact bus stop in whose catchment area they live (while in reality they would sometimes walk a longer distance to catch a more direct bus). This method is however the only way to generate a completely disaggregated OD-matrix with the available data.

The assignment of trip information to the TAZ's is a complex operation that cannot be implemented interactively in the PSS. The results can be used for analysis, but their assumption values can therefore not be changed by the end-user. New trip information can be implemented, but only by expert users of the system, with the help of external database management tools. The TAZ's are therefore not used for further interactive analysis by the end-user of the PSS and are only used for trip calculations.

4.3.3 Planning Analysis Zones (PAZ's)

Because all TAZ's differ in size and many are very large, it is difficult to interpret the results of planning analysis if these are presented on TAZ level. TAZ's are also connected directly to existing bus stops, while in the PSS the location of bus stops should be negotiable by the end-user. A different zoning system, which can provide information on a scale level that is the same throughout the whole PSS, is therefore introduced. These zones are called Planning Analysis Zones (PAZ's), which are defined in the same analogy of TAZ's. The PAZ's should however be equal in size and homogeneous in properties, to be able to compare them easily.

The equal size structure can be achieved by introducing a grid system that cuts the extent of the analysis area in equal parts. This grid can be created in several geometrical forms, from which a hexagonal grid is the most convenient. The advantage of a hexagonal grid over a square grid is that the distance from the centre of a cell to all adjacent cells is equal and that the cells are more homogeneous because of their closer resemblance with a circle, which has equal distances to all edges.

The PAZ grid is constructed in the following way:

1. A grid of hexagons with a diameter of 200 meters is constructed using ArcGIS. This size is chosen arbitrarily, but it compromises between zones that are too large for interpretation and zones that are too small for further analysis.
2. The grid is overlaid with a buffer zone of 2000 meters around all bus routes, following the same analogy as with the TAZ's. The hexagons that intersect with this buffer zone are the only zones in reasonable reach of the public transport system, and will therefore be the zones from which most transit users originate. These zones are used as the PAZ's
3. The PAZ's are each assigned to the sector that they are in and to the bus stop that is closest to them, as the crow flies. They are assigned disaggregated attribute information of the sectors, like total population and trip production, based on the total amount of PAZ's

intersecting with a sector. Bus stop attributes are connected directly to the PAZ's and the total production of all PAZ's in reach of a bus stop is summed as an attribute for this stop.

Due to this way of disaggregation, the individual PAZ's have the properties and attributes of the exact sectors they are in, which enables more variation in indicator calculation. When grouped at bus stop level, they are comparable in shape and size to the TAZ's.

The PAZ's will be used by the end-user of the PSS to review the effect of policy scenarios in the form of indicators and index scores.

4.3.4 Basic PSS content

The visual, network and planning analysis layers described above are displayed in Figure 8 in several independent layers and in a total overview. The user interface is not necessarily the overview displayed in Figure 8, because the end user or a moderator can select the relevant layers for the activity he is using the PSS for. The colours and zoom level can also be changed based on personal preferences. No extra scales, legends or cartographic details were added to the maps presented in this figure and further in this report, in an effort to represent the view of the end-user as good as possible.

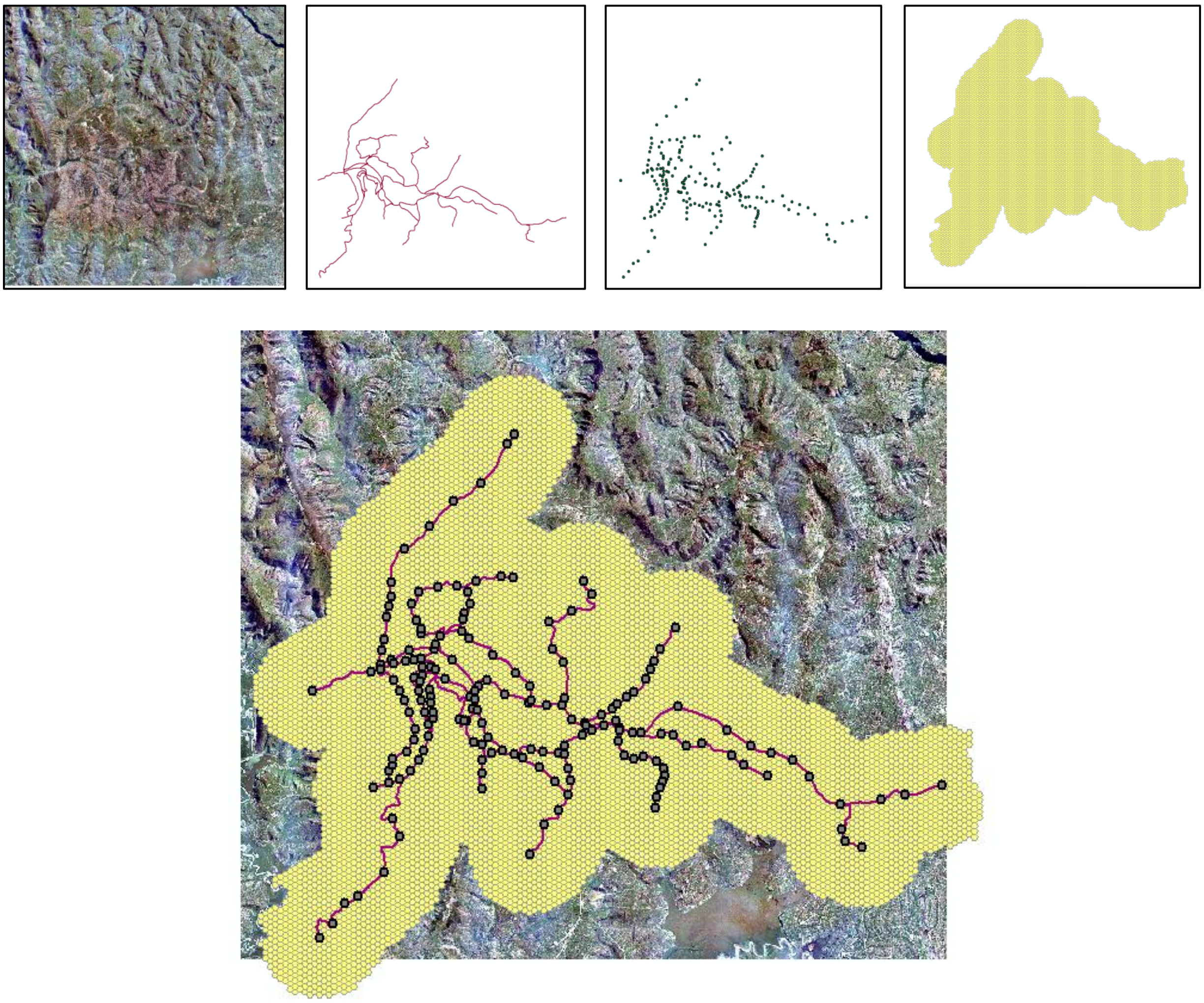

Figure 8: Overview of basic PSS content

4.4 Development of indicators

Based on the theory laid out in chapter 2.3.3, the design of indicators for this PSS prototype is described in this section. A selection of relevant indicators is made using knowledge from literature and requirements stated during the field study. These indicators are further developed in models and formulas.

To keep a clear overview of the requirements for these indicators, the workflow of the PSS from Figure 7 is adapted for each indicator in this section. The workflows display the required input data, the selected basic content, the static or dynamic assumptions and the scenarios that can be composed using these assumptions. In the indicator presentation section, the available outputs for review by users are displayed too, to give an overview of the user interface.

4.4.1 Indicators for assessing public transport in Kigali

The evaluation indicators proposed in section 2.3.3 can be implemented in the PSS in an adapted way, by giving the end-user the opportunity to choose the desired indicators and to assign weighing factors. For every individual indicator, result reports, maps and graphs can be generated in the PSS based on their calculated value after a policy implementation. Policy makers can choose to assign weights to individual indicators to calculate an aggregate evaluation index. This reflects the relative importance a policy maker can assign to the interests of different stakeholders.

It is mentioned in a revealed preference survey by Japan Engineering Consultants Co. (2004) that more than 80% of respondents in Kigali were unsatisfied with the public transport service quality at that moment. According to that study, this mainly had to do with price (36% of passengers mentioned this), the informality of the service (23%) and the behaviour of drivers and assistants (15%). The most frequently given recommendations for improvement of the service were to lower fares (45%), improve roads and stops (30%) and increase rules and regulations (21%). (Japan Engineering Consultants Co., Ltd., 2004)

From these results, the attributes of Affordability and Availability seem to be most important for the current situation in Kigali. Affordability could become a problem in the future when fare prices might rise due to formalization of the system and the effect of policies on affordability should therefore be monitored. The Availability (and Accessibility) indicator indicates the complaints and recommendations about informality, improvement of infrastructure and regulation. It is indicated in the same report that walking distance towards a bus stop and average waiting time scored relatively well in Kigali City at the time. It is however important to remain monitoring these attributes while applying policy changes.

Acceptability is one of the main drivers that urge the government to rationalize the system, but it is probably the least important issue for most current users when it comes to the quality of the system. Only 15% of people mentions driver behaviour as an important complaint and comfort is not mentioned at all. Acceptability is however taken into account in the PSS to be able to cover all quality attributes, which is also valuable for policy decisions that might affect acceptability negatively. As a good service level, defined here as the availability of seats in a vehicle at the stop, is an important reflector of acceptability, it is selected to be used in this PSS.

The willingness-to-pay for informal and formal transport is hard to define properly. A brief calculation is described in the data collection report developed by SSI Engineers (Rwanda Ministry of

Infrastructure, 2011). They provide a utility function analysis based on stated preference research, in which they further elaborate on the potential modal shift after introducing some kind of formal bus transport. This calculation is however not validated and because it lacks a clear spatial component, the willingness-to-pay and and price-elasticity is left out in the analysis in this research.

In the case of Kigali, the capital costs of buying new buses, which is an important indicator for operators and governments, is calculated into the fare price through the cost price of public transport. This calculation is therefore introduced as a separate indicator in the PSS, together with the total amount of vehicles of each type. Policies might change the composition of the vehicle park and the total employment in the sector, which should therefore also be monitored in an indicator.

Air pollution and congestion are not taken into account in this PSS, as the required data to calculate these indicators is not available and the model is not detailed enough to do this. Social exclusion, which is also a concern of the government, is also not accounted for, but policy makers can choose to review this phenomenon by adding value to for example accessibility or affordability.

Based on the considerations stated in this section and the previous ones, the passenger indicators in Table 3 will therefore be part of the PSS development. This is not a complete set of all possible indicators, but forms a case study for Kigali in this PSS prototype.

Attributes	**Passenger indicators**
Affordability	Average expenditure of income on transport
Availability	Average headway
Accessibility	Pre-transport service area of a stop
Acceptability	Passenger demand satisfaction

Table 3: Passenger indicators for Kigali City PSS

These indicators are chosen because they can form a clear index that can be attatched to a map of sectors or bus stops. This asks for specific indicators than can be measured in an unambiguous way. The set of indicators is comparable to the set that Gomide, Leite, & Rebelo (2005) described for the assessment of the public transport in Belo Horizonte in Brazil. These indicators are very useful for evaluation of problems in developing country and are suitable for use in a GIS environment.

The four indicators are each presented as a normalized score. This means each score will have a value between 0 and 1, because the value of the indicator is compared with a maximum or minimum value. A synthetic index, which will be called the *passenger evaluation index,* will be developed to connect these four scores in a final score, which is useful in the early planning process.

Next to these passenger indicators, a few other indicators are important for the stakeholders operator and government. These indicators, which are shown in Table 4, overlap a great deal because of the shared interests of operators and government, so they are displayed together.

Attributes	Operator/government indicators
Demand satisfaction	Total vehicle capacity per link compared to demand
Vehicle park size	Amount of buses of each type
Total employment	Amount of people working to operate the vehicle park
Fare price	Price of fares per route based on various indicators that effect the price per kilometre
Capital investment	Total costs of extra vehicles
Budget satisfaction	Total investment costs relative to a pre-set budget.

Table 4: Operator/government indicators for Kigali City PSS

4.4.2 Indicator calculation

In this section, the development of the indicators is first described and presented in a design model in the shape of the CommunityViz workflow. This is followed by a summary of the formulas implemented in CommunityViz. Screenshots of the implemented indicator in the software are presented to show the presentation of indicators to the user.

4.4.2.1 Affordability

Definition

The affordability indicator that is selected compares the inevitable transport expenses per person with the average income per zone. This way of defining the indicator is based on the assumption that:

- per household only one person earns the income;
- this person is also the only person in the household travelling to and from work;
- this person is making this journey usually around 6 times per week back and forth (which is the most frequently mentioned trip frequency in a survey done by SSI Engineers (SSI Engineers, 2011)).

The latter assumption is set to be chosen interactively by the user in the PSS.

There are no clear figures available for the household income per sector in Kigali. SSI Engineers have however conducted a survey in which they asked around 1000 respondents about their income class (SSI Engineers, 2011). Although the size of this sample is not significant, an estimation of the income differences per sector can be derived by averaging the income classes mentioned in this survey. This data should however only be used as an example for this prototype. Real income data should be added to the system when it becomes available in the future.

The transport expenses of a person are based on the amount of times a trip is made (already mentioned) multiplied with the fare price, which is aggregated to a flat fare per route in the system. This fare price can either be set directly by the user of the PSS or be calculated in a complex process. The complex calculation adds further detail to the decision-making process, as the effects of cost price fluctuations can be seen in the fare prices.

Users are provided with the possibility to interact with the fare prices, resulting in different flat route fares. These fares per route are presented directly to the user in a chart, or can be reviewed through the affordability score per PAZ.

The design model visualizing the construction of the indicator is presented in Figure 9.

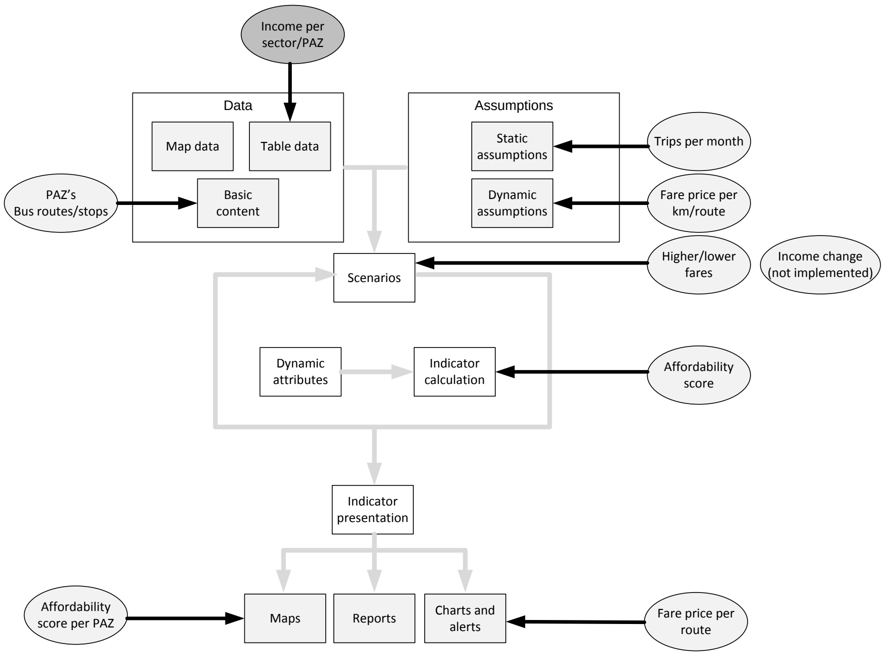

Figure 9: Design model of affordability indicator

Calculation

The affordability level per PAZ is calculated with equations 4.1 and 4.2.

$$L_{afford,PAZ} = \frac{F_{av,bus\ stop} * T_{month}}{I_{PAZ}} \tag{4.1}$$

$$L_{afford,PAZ} = \frac{\sum F_{route}/_{n_{routes}} * T_{day} * n_{traveldays}}{I_{PAZ}} \tag{4.2}$$

where:

$L_{afford,\ PAZ}$ = The affordability level per PAZ (travel expenses as percentage of average income)
$F_{av,\ bus\ stop/route}$ = The average fare price per bus stop or route
$T_{month/day}$ = The number of trips per month or day
n_{routes} = The number of routes per bus stop
$n_{traveldays}$ = The number of travel days per month
I_{PAZ} = The average income per PAZ

The average fare price per bus stop is assumed to be the average of the fares of all routes passing through it. This average fare is paid by the traveller on each trip from this bus stop and has to be multiplied by the number of trips per day and working days per month to find the total travel expenses.

These total travel expenses are divided by the average income in a PAZ (which is deducted from the income in the sectors). This results in an affordability level, showing the percentage of the household income that is spent on public transport travel.

This affordability level can be normalized into an affordability score, by comparing it to a user-configurable parameter for the maximum percentage of income that should be spent on transport. This is shown in equation 4.3.

$$S_{afford} = \frac{E_{max} - L_{afford,PAZ}}{E_{max}} \quad (4.3)$$

where:

S_{afford} =	Affordability score per PAZ (normalized)
E_{max} =	Maximum transport expense level
$L_{afford,PAZ}$ =	Affordability level per PAZ

The maximum transport expense level is set to a default of 25%, which is one of the upper boundaries of income spent on transport in Sub-Saharan Africa (Olvera, Plat, & Pochet, 2008). Ideally, the maximum should therefore be kept much lower in policies that aim for better affordability.

To make sure the score stays between 0 and 1, even when the affordability level exceeds the maximum transport level, the minimum affordability score is set to 0 by setting a maximum function:

$$S_{afford} = Max(0, \frac{E_{max} - L_{afford,PAZ}}{E_{max}}) \quad (4.4)$$

This maximum function is set in the same way for all scores in the PSS without further notice.

The affordability score can be compared with other PAZ's individually, or aggregated in the passenger evaluation index, which will be presented later.

Presentation

The affordability score per PAZ can be displayed best in the map view. Charts or reports displaying the fare price per route can also be useful in the planning process, so can are also be presented on request.

Limitations

This affordability score gives an impression of the affordability of the fare prices in the area of a stop. It does however not take into account that most users have to pay multiple fares for transfers during their trip and does not weigh the fare prices based on the amount of trips made with each route. The income figures used are furthermore not very reliable and are aggregated over the entire sector. This indicator should therefore be supplemented with better data to make good estimations.

Implementation

The calculation of the affordability score is implemented in CommunityViz by allowing the user to set the kilometre price that is used to calculate fare prices (although it is also possible to make this kilometre price based on a set of parameters, which is described later), the amount of trips per person per day and month and the maximum transport expense level. The values of these assumptions can be changed interactively, as is shown in Figure 10.

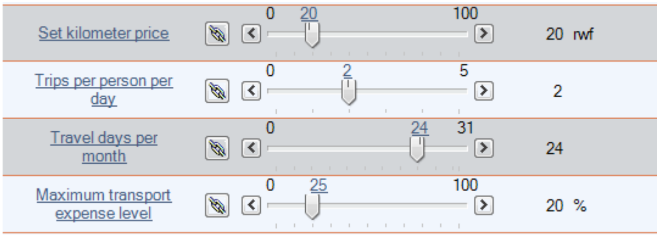

Figure 10: Affordability assumptions

The result of the calculations in the PSS is presented as a normalized affordability score for each PAZ, as shown in Figure 11. These results can of course be explored by zooming in and reviewing the properties of each PAZ.

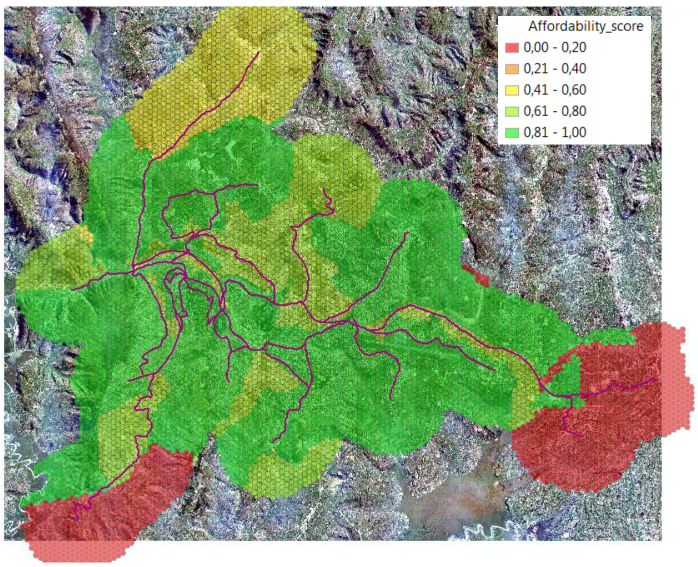

Figure 11: Affordability score per PAZ in CommunityViz

4.4.2.2 Availability

Definition

Availability is defined here as the availability of vehicles to users, which is measurable as the average headway of arriving vehicles at a stop and therefore a surrogate measure of the average waiting time for travellers (which is actually half of the time headway on average).

These time headways are based on the average speed of vehicles in the network and the maximum waiting times of vehicles at stops and terminals. The assumption used here is that maximum waiting times are enforced everywhere and that operators keep to these waiting times at all times. As they value full vehicles and always tend to wait for more passengers, the maximum waiting time will often also be the actual waiting time.

The design model visualizing the construction of the indicator is presented in Figure 12.

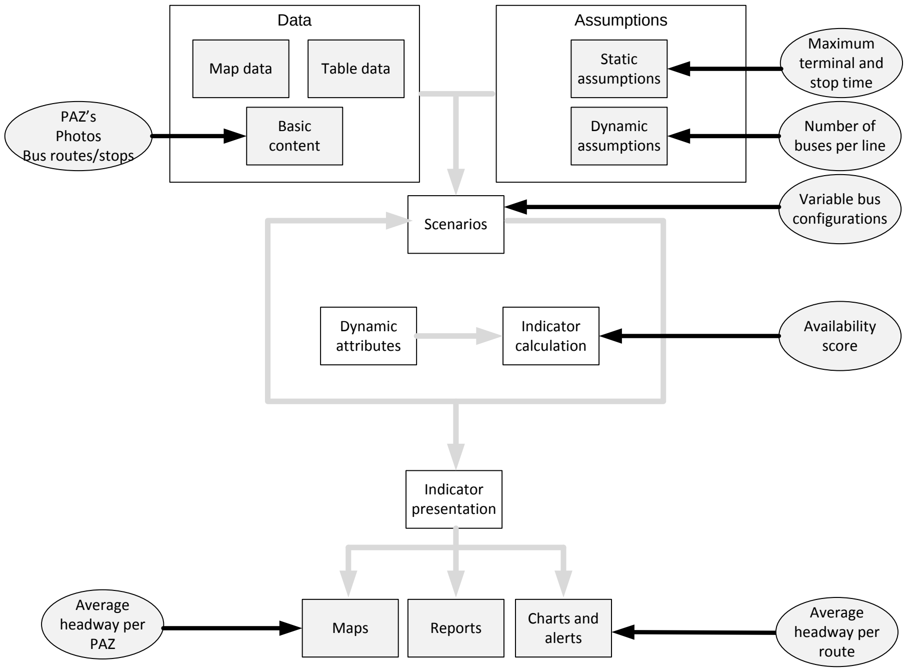

Figure 12: Design model of availability indicator

Calculation

The time headway for each route is calculated by dividing the route cycle time by the amount of vehicles on the route, that are assumed to be distributed evenly (assuming that maximum waiting times at stops and terminals are enforced through the whole system). Cycle time in its turn is found by taking the full trip length from begin terminal to end terminal and back and dividing it by the average vehicle speed. The maximum waiting time at each stop is added to this travel time, as well as the maximum terminal time at both ends. This results in the total time it takes a vehicle to complete a cycle. When divided by the number of vehicles, a time headway approximation per route can be found. This is summarized in equations 4.5 and 4.6.

$$H_{time,line} = \frac{T_{cycle}}{n_{vehicles,route}} \qquad (4.5)$$

$$H_{time,route} = \frac{L_{route}/_{V} + T_{terminal} * n_{terminal} + T_{stop} * n_{stop}}{n_{vehicles,route}} \qquad (4.6)$$

where:

$H_{time,\ route}$ = Route time headway
T_{cycle} = Total cycle time
$n_{vehicles,\ route}$ = Number of vehicles per route
L_{route} = Length of a route (round trip)

V = Average speed of vehicles
$T_{terminal/stop}$ = Maximum waiting time at terminal or bus stop
$n_{terminal/stop}$ = Number of terminals or stops per route

The time headway per bus stop is calculated in a slightly different way, because time headways cannot be added up or averaged. Assuming the equal distribution of vehicles on all routes, the average headway per stop can be found by simply dividing the reviewed period of time (an hour for example) by the total amount of vehicles stopping there in this time period, as in equation 4.7:

$$H_{time,stop} = \frac{T}{\sum_{routes} \frac{T}{H_{time,route}}} \tag{4.7}$$

where:

$H_{time, stop}$ = Stop time headway
T = Reviewed period of time in minutes (standard 1 hour)
$\sum_{routes}$ = The sum over all routes passing that bus stop
$H_{time, route}$ = Route time headway

This results in the time headway per stop per direction (usually the same for both directions). This stop time headway is transferred directly to the PAZ's that use this bus stop.

We can transfer the stop time headway into an availability score per PAZ by comparing it with a user-configurable maximum time headway, as described in equation 4.8.

$$S_{avail} = Max(0, \frac{H_{max} - H_{time,PAZ}}{H_{max}}) \tag{4.8}$$

where:

S_{afford} = Availability score per PAZ (normalized)
$H_{time, PAZ}$ = Time headway score per PAZ, which is selected from the nearest stop ($H_{time, stop}$)
H_{max} = Maximum time headway

Presentation

The average headway per PAZ can be presented best in a map view, while the average headway per route can be presented to the user in a chart or report.

Limitations

Congestion is not accounted for directly in the calculation of headways in this indicator, but it can be represented by the user when required, by adjusting the average vehicle speed.

As mentioned earlier, the availability score is based on the assumption that a traveller will take any first bus arriving. This will probably be the case for most stops, as a lot of travellers will have to transfer to another bus during their trip anyway. They will take the first available option to speed up their journey.

Implementation

In the calculation of the availability score, the end-user can mainly vary the operational characteristics of the vehicle park. These are the maximum stop and terminal waiting time and the average speed on the whole network, and the amount of minibuses, coasters and large buses per route. When these are changed interactively, this changes the average headway on all routes, resulting in a changing availability level. The maximum time headway can also be selected, to determine the normalized availability score that is assigned to each level. An overview of the variable assumptions, including an example of the amount of vehicles on one of the routes (Remera-Masaka) is presented in Figure 13.

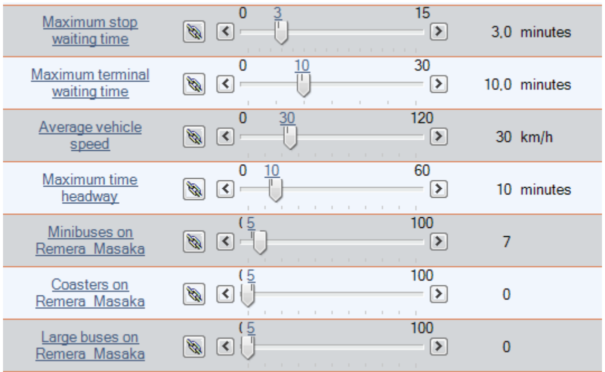

Figure 13: Availability assumptions

The availability scores per PAZ can be reviewed in the map overview, as shown in Figure 14.

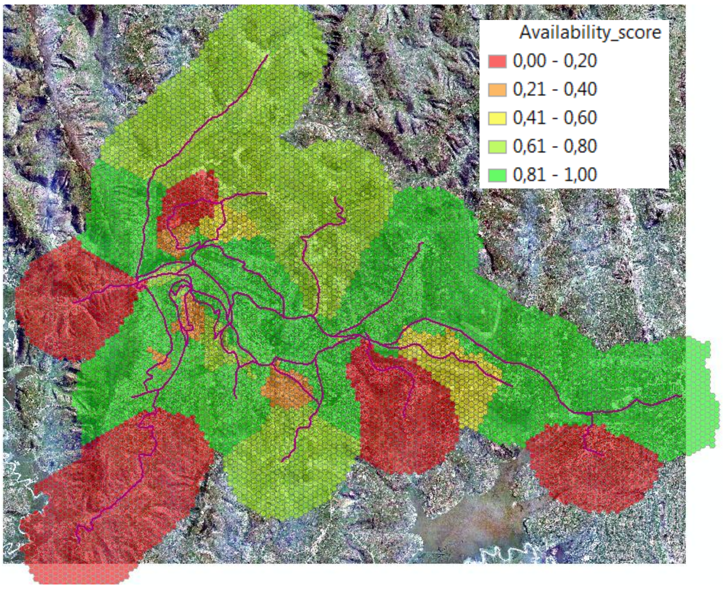

Figure 14: Availability score per PAZ in CommunityViz

4.4.2.3 Accessibility

Definition

The accessibility indicator will look at the distance of each PAZ towards the closest bus stop. This distance, which is often called the pre-transport distance, will usually be travelled on foot or sometimes by chartering a motor-taxi. We assume pre-transport on foot in this study, as this will be the option selected by the poorest population.

All PAZ's lie at a maximum of 2000 metres from a transit route, because they were selected in this way in an earlier stage. Because the bus stops in Kigali are rather close together, this will almost always also be the maximum distance towards a bus stop, although some areas are found to have a slightly larger distance towards a bus stop. The maximum distance is therefore selectable for the end-users, to give them the opportunity to make choices on the maximum walking distance that is still flagged as accessible.

The design model visualizing the construction of the indicator is presented in Figure 15.

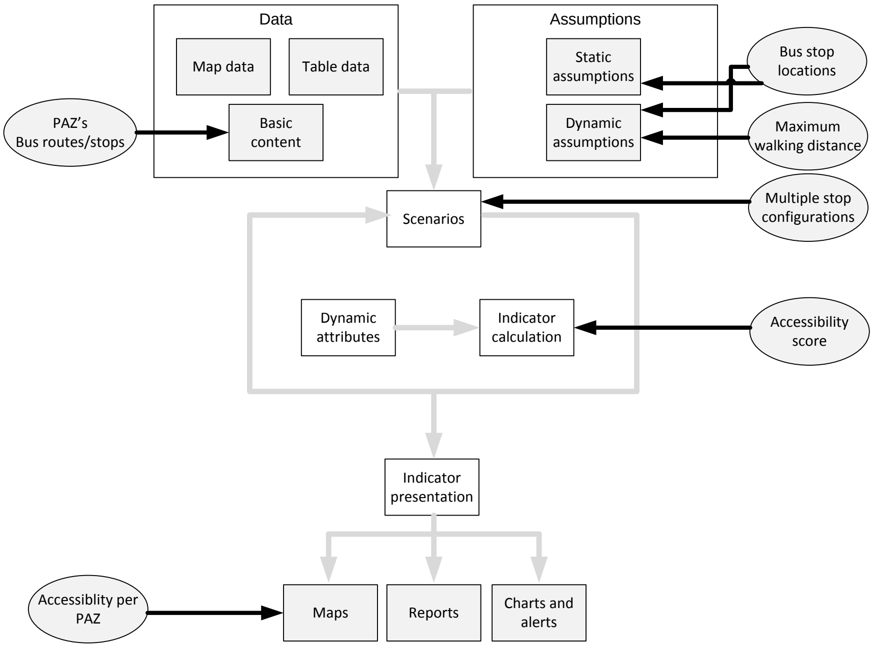

Figure 15: Design model of accessibility indicator

Calculation

Distance is calculated by an internal formula of CommunityViz, which basically runs a lookup algorithm to find the bus stop closest to a PAZ. The distance from the centroid of the PAZ towards the bus stop is taken to be able to define the total encroachment distance. This distance can be compared to a user-defined maximum distance, to result in an accessibility score as shown in equation 4.9.

$$S_{access} = Max\ (0, \frac{D_{max} - D_{stop}}{D_{max}}) \quad (4.9)$$

where:

S_{access} = Availability score per PAZ (normalized)
D_{stop} = Walking distance towards the closest stop
D_{max} = Maximum walking distance

Presentation

The accessibility score can be reviewed on a map, where it displays relatively obvious results. High accessibility scores are found around bus stops and scores are decreasing in circles. This information is therefore most valuable in combination with other scores in the passenger evaluation index.

The value of the score will change when the user changes the maximum acceptable encroachment distance or when the location of bus stops is changed. The score is therefore useful for optimizing the location of bus stops for optimal service level.

Limitations

Ideally, this distance should be calculated using the network, to be able to estimate the real walking distance over roads in Kigali. This might be a lot longer than the Euclidian distance, because the topography of Kigali contains many hills and wetlands. Due to limitations in the calculation capabilities of CommunityViz this is however not possible, and the straight line distances are used as a surrogate measure.

Implementation

As the accessibility score indicator is only dependant on the measured distance towards a bus stop and the maximum walking distance for a passenger, only the latter can be set interactively in by the user. This is shown in Figure 16.

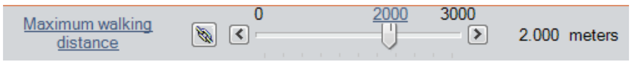

Figure 16: Accessibility assumptions

This leads to the accessibility scores per PAZ as presented in Figure 17.

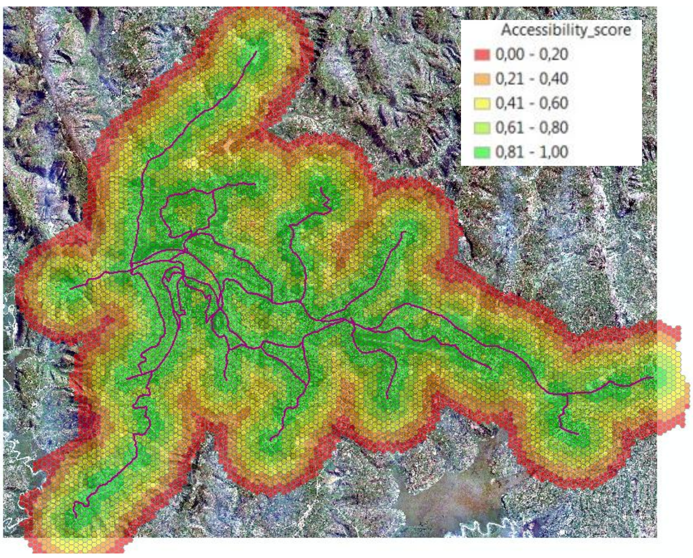

Figure 17: Accessibility score per PAZ in CommunityViz

4.4.2.4 Acceptability

Definition

Acceptability is measured in a lot of different ways, but this indicator focuses on acceptability of service level. It measures the ratio between the production of trips from the areas a bus stop serves and the capacity offered by the various bus routes.

Using average time headway and the assumption of equal distribution of all vehicle sizes, the average bus capacity per hour of a route can be estimated. This supply parameter can be compared with the demand for public transport, which is available in the form of OD matrices per sector. This demand information is disaggregated as described in section 4.3.3, to generate a service level acceptability score per PAZ.

The design model visualizing the construction of the indicator is presented in Figure 18.

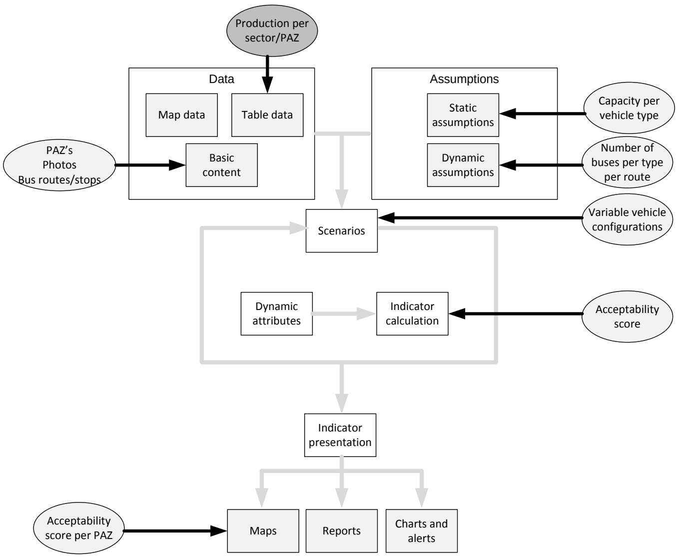

Figure 18: Design model of acceptability indicator

Calculation

For each bus stop, the total production from all PAZ's that use this bus stop in the peak hour is summarized in equation 4.10.

$$P_{stop} = \sum_{PAZ} P_{PAZ} \tag{4.10}$$

where:

P_{stop} = Total production of trips at this bus stop
$\sum_{PAZ}$ = The sum over all PAZ's from which the selected bus stop is the nearest
P_{PAZ} = Total production of trips at each PAZ

This hour production per bus stop is compared with the total hour capacity of buses at this stop to define the level of acceptability in equations 4.11 and 4.12.

$$L_{accept,stop} = \frac{P_{stop}}{C_{stop}} \tag{4.11}$$

$$L_{accept,stop} = \frac{P_{stop}}{\sum_{routes} C_{type} * n_{vehicles,type}} \tag{4.12}$$

where:

$L_{accept,\ stop}$ =	Acceptability level of the stop.
P_{stop} =	Total production of trips at this bus stop
C_{stop} =	Total capacity of all buses arriving at that stop
$\sum_{routes}$ =	The sum over all routes passing that bus stop in that hour
C_{type} =	Capacity per vehicle type
$n_{vehicles,\ type}$ =	Number of vehicles passing per route per type

Low acceptability levels below 1 indicate that capacity exceeds production, which will leave open spaces in the vehicle. Levels closer to and above 1 indicate that production exceeds capacity and some trips will not be served.

This results in an indicator that indicates whether the intended trips from each PAZ are served by the system in the peak hour. It would be acceptable when all travellers can be served during a peak hour, so values of the acceptability level indicator higher than 1 are given the lowest acceptability score of 0. For values below 1, the acceptability score should increase with lower acceptability level, as shown in equation 4.13.

$$S_{accept} = Max\ (0, \frac{F_{load,max} - L_{accept,stop}}{F_{load,max}}) \tag{4.13}$$

where:

S_{accept} =	Acceptability score per PAZ (normalized)
$L_{accept,\ PAZ}$ =	Acceptability level of the PAZ.
$F_{load,max}$=	Maximum load factor

Presentation

The acceptability score is calculated per bus stop, but can be transferred back directly to the PAZ's. PAZ's that are close together will therefore often have the same acceptability score, which gives information about the acceptability of service level in the area of that bus stop. This can be presented in a map per PAZ. More information about the balance between demand and supply can be presented with another indicator for overcrowding, which is described later.

Limitations

A limitation of this indicator is the fact that it only compares demand per TAZ with the total empty vehicle capacity. It does not take into account the modelling of actual intensities of buses, which would be a much more complicated and uncertain measure that would require much more detailed data. This however results in the fact that, even with very acceptable scores of this indicator, buses might still be overcrowded or too full to take on the demand. The maximum acceptable ratio might therefore need to be set much lower than the obvious score of 1 to be acceptable to passengers.

Although an acceptability score closing towards 1, which would indicate a lot of overcapacity, is positive for passengers, this is negative for operators, as operating this route would be very unprofitable. Operators should therefore try to minimize this score, while at the same time not allowing acceptability level to reach 1. This could potentially also be represented in a separate load factor indicator for operators.

Implementation

The acceptability level depends, just as the availability level, on the amount of vehicles per bus route. This is set interactively by the end-user, just as the available capacity per vehicle type. Although the latter is usually constant, this is set to variable to maximize the flexibility of the planners. The acceptability level further depends on the total production per zone, but this can only be changed by an expert user of the PSS. The end-user can further vary the maximum load factor, to score the acceptability level into a normalized acceptability score. All assumptions are presented in Figure 19. Due to the inability of CommunityViz to work with decimals in assumptions, the maximum load factor is set as a percentage, where 100% means a load factor of 1.

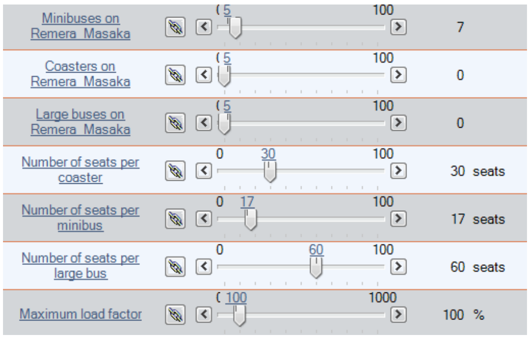

Figure 19: Acceptability assumptions

The normalized acceptability score per PAZ is presented in Figure 20.

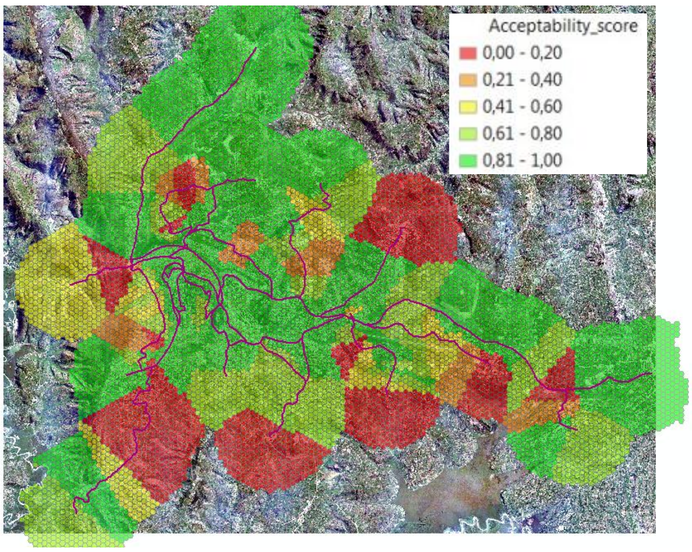

Figure 20: Acceptability score per PAZ in CommunityViz

4.4.2.5 Passenger evaluation index

Definition

The passenger evaluation index groups the four evaluation scores that are relevant to passengers together in one index score. This score is a simple average of the four individual scores, but can be weighed by the end-user of the PSS. Weights can be assigned to all scores to reflect the needs of the passengers based on a stated preference research, or can be assigned by policy makers to reflect the importance of policy goals. Just as the other evaluation indicators, this score is linked to the PAZ's, which enables the user to quickly select PAZ's that have lower scores and are therefore areas of interest. The passenger evaluation index functions as a first impression in the system evaluation, which invites for further assessment.

Calculation

The passenger evaluation index score is calculated by adding the four passenger scores which are multiplied by an assigned weight. This figure is divided this by the sum of all weights, which results in a score between 0 and 1. This is shown in equation 4.14.

$$S_{passenger} = \frac{\sum_a S_a * W_a}{\sum_a W_a} \qquad (4.14)$$

where:

$S_{passenger}$ =	The passenger evaluation index score per PAZ
$\sum_a$ =	The sum of all passenger indicators
S_a =	The passenger indicators Affordability, Availability, Accessibility and Acceptability
W_a =	The weights assigned to each passenger indicator

Presentation

The score of the index is presented in the map view, to provide a good overview of the underscored PAZ's in the system. All passenger evaluation indicators, including this evaluation score, are presented in a chart that gives an average score for the whole system. This can be used as a first impression of the worth of a scenario, but should not be used as a major indicator.

Limitations

The aggregation of the earlier scores in this index leads to information loss and can distort the scores of certain PAZ's. The index should therefore only be used to get a first impression of the effects of policy measures and to select areas of interest. Further evaluation should be done by looking at the individual indicators.

Implementation

The weights that are assigned to the various scores can be set interactively by the end-user, by choosing a value between 1 and 10 for every score. In the example in Figure 21, different weights are set for the various scores, but it can be seen that the standard value for every weight is 1 (the underlined figure above the slider).

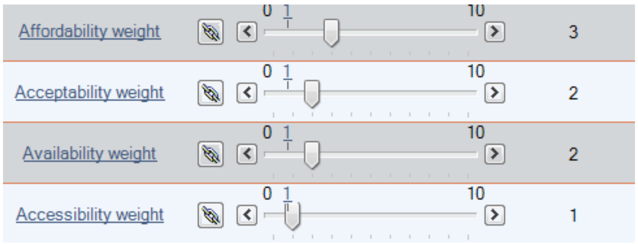

Figure 21: Index weight assumptions

All passenger evaluation scores can be aggregated over the whole system, which gives an impression of the average power of a scenario. Although this has not much statistical power, it can give a first impression to the end-user. These aggregated scores are seen in Figure 22.

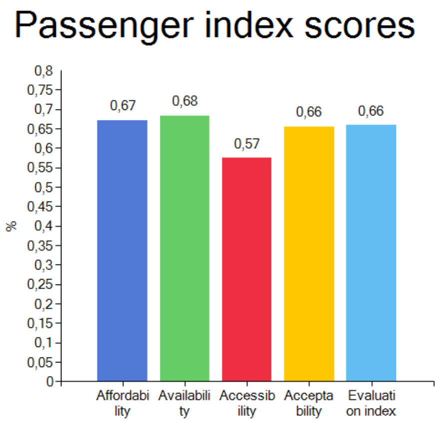

Figure 22: Average passenger index scores

With the weights set as in Figure 21 and the four scores also unchanged from the previous sections, the passenger evaluation index score is presented in Figure 23. This score is of course very much dependent on the combination of weights and the assumptions in the individual scores, but it gives a clear overview of possible problem areas in the public transport system.

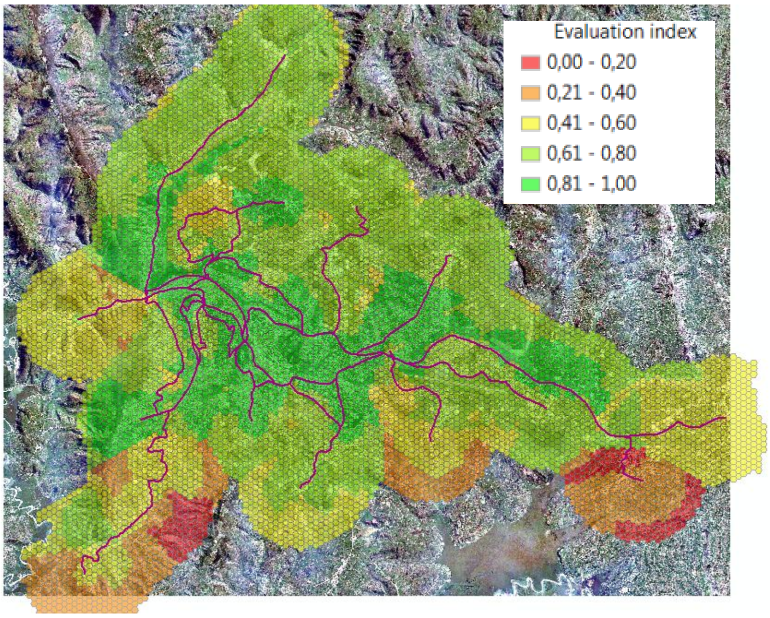

Figure 23: Passenger evaluation index per PAZ in CommunityViz

4.4.2.6 Demand satisfaction

Definition

For passengers, the public transport system should be able to serve all trips that people want to make in the network. This demand for trips must be satisfied by providing enough supply in the form of bus seats. For operators however, the total supply capacity should also not be too much larger than the demand, as this would lead to unprofitable operation of routes. The satisfaction of public transport demand should therefore be monitored closely.

The disaggregation of the trip data per bus stop results in a complete OD matrix, with trips between all TAZ's (which are related to the bus stops). Because trip distribution between all TAZ's is known, only the trip assignment is yet required to find the intensity of people travelling on all links.

These trip attraction and production figures for the public transport mode can be assigned to the network using the software tool Flowmap, which was described in section 2.3.1.1. Travellers are assumed to choose the most direct path through the system, so the traffic is assigned using an all-or-nothing algorithm based on travel distance.

The assigned travel demand on a link can be compared to the offered vehicle capacity during the peak hour. When the demand for transport is higher than the capacity on some links, this might lead to overcrowding of vehicles and loss of service quality. When the supply capacity is much higher than the demand, this leads to overcapacity and operational losses. A good balance between supply and demand is therefore an important goal of operators and is valued by both the government and the passengers.

The design model visualizing the construction of the indicator is presented in Figure 24.

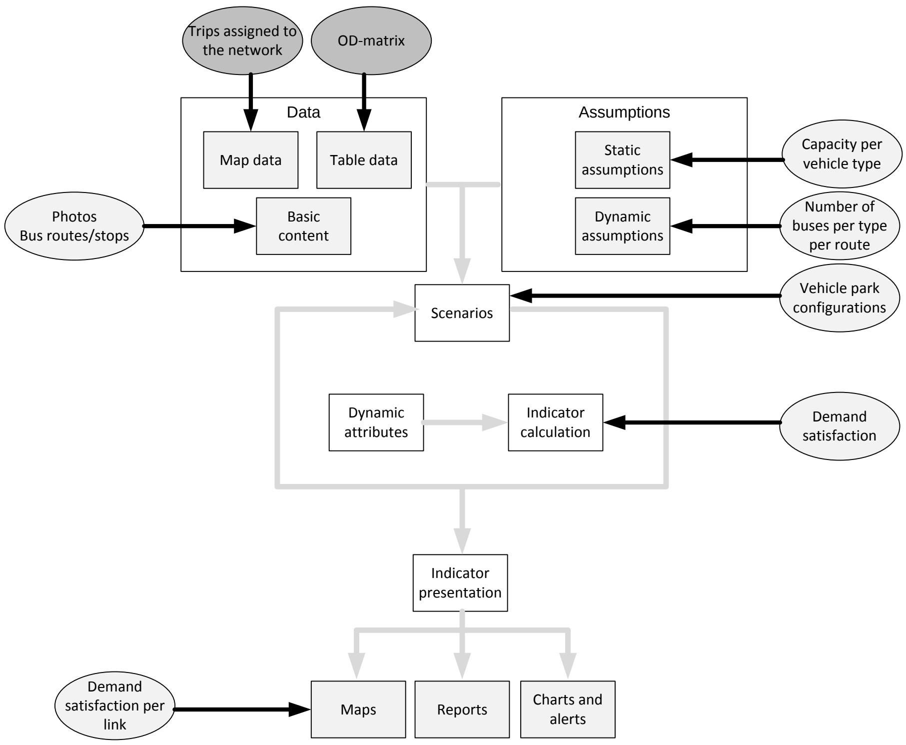

Figure 24: Design model of demand satisfaction indicator

Calculation

The assigned trips per network link can be compared with the offered capacity supply per link. This gives an impression of how sufficient the offered hour capacity per link is and where overcrowding might take place. This is done in equations 4.15 and 4.16.

$$L_{satisfaction,link} = \frac{D_{link}}{C_{link}} \tag{4.15}$$

$$L_{satisfaction,link} = \frac{D_{link}}{\sum_{routes} C_{type} * n_{vehicles,type}} \tag{4.16}$$

where:

$L_{satisfaction.link}$ =	The level of demand satisfaction of the link
D_{link} =	Demand assigned to each link
C_{link} =	Vehicle capacity supply on each link, in both directions
$\sum_{routes}$ =	The sum over all routes passing that link in an hour
C_{type} =	Capacity per vehicle type
$n_{vehicles,\ type}$ =	Number of vehicles passing per route per type

This results in a ratio that depicts the demand satisfaction of a link, when all demand is assigned to the available vehicles. A value below 1 indicates complete satisfaction of the demand, where values close to 0 even depict overcapacity. Values larger than 1 indicate overcrowding of vehicles or trips not being served. This ratio is not aggregated into a score, as it describes a direct relation that should be reviewed as such.

Presentation

Because of the straight relation to the links, this indicator should be presented in a map of all links in the network. This gives a clear picture of the areas were demand exceeds capacity and vice versa.

Limitations

The All-or-nothing assignment of trips does not account waiting times and does not correct for the inconvenience and travel time loss of transferring, which might make people change their travel patterns. Stops with a clear transfer function or multiple bus stops in an area for different directions might also change the real assignment of trips in reality. It is therefore advisable to include a better assignment procedure in future models. This might require microsimulation with more specific trip information and the collection of more traffic count data.

Implementation

The parameters available to the end-user that can vary supply capacity in the system are already described in the acceptability score section (section 4.4.2.4). The only extra data added to the calculation of this indicator is the number of assigned trips on every link. This is available for three distinct traffic periods: the morning peak hour (AMPH), the off-peak busy hour around noon

(Offpeak) and the afternoon peak hour (PMPH). Which of these peak hours and their assigned trips is reviewed, can be set by the end user with the assumption shown in Figure 25.

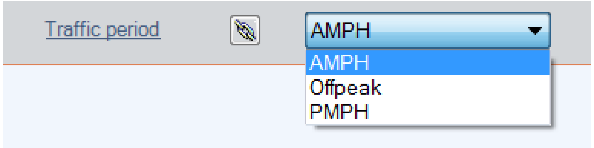

Figure 25: Interactive selection of reviewed traffic period

After the selection of the traffic period, the trips in this period are assigned to the network, as is shown in Figure 26 for the AMPH. As these trips are only used as an intermediate result, no legend is provided for this map. The width of the bars in the network represents a number of passengers travelling on that link in both directions.

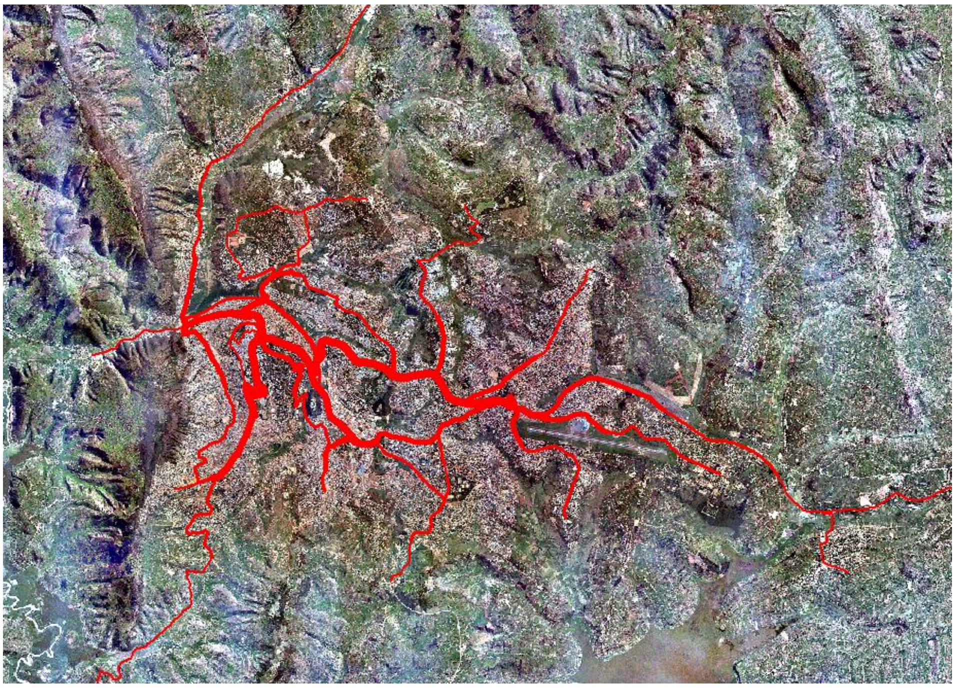

Figure 26: Assigned flows in the morning peak hour (AMPH)

When this assigned demand is compared with the supply that is available using the equations above, this results in the demand satisfaction ratio per link as shown in Figure 27. A bright colour scale is used here to clearly define the areas of interest for further development. The green and (to a certain extent) yellow links are acceptable or lightly crowded, while the orange and red links are heavily overcrowded. The blue links on the other hand can become unprofitable due to the overcapacity on these links.

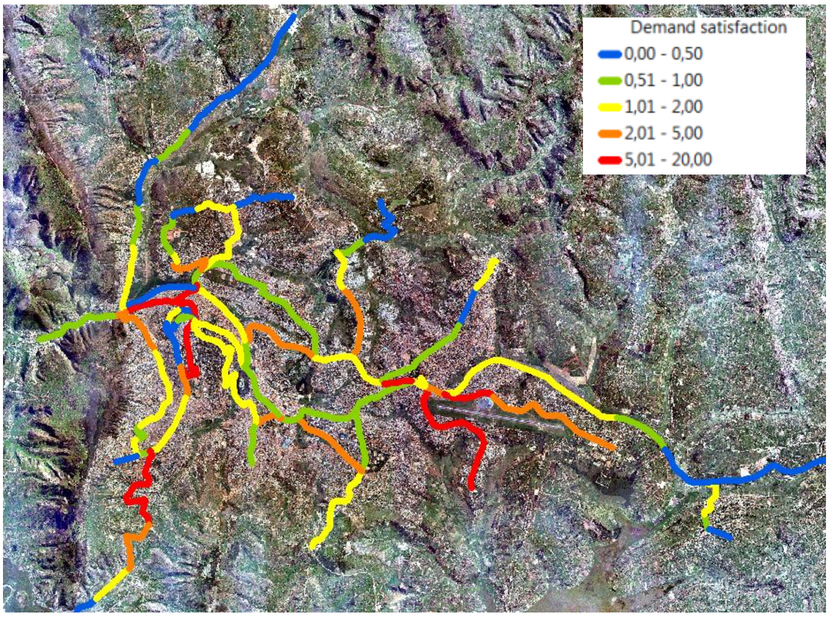

Figure 27: Demand capacity ratio per link

4.4.2.7 Vehicle park operation

Definition

The vehicle park operation indicator set is the most interactive set of the PSS. The vehicle park, which in Kigali consists of a lot of privately owned vehicles in three main types, is an important steering possibility of the government in policies. The amount of vehicles of each type that are licenced to operate each route can be changed easily, by issuing a limited amount of licences per route and per type.

This can be implemented in the PSS by selecting the amount of vehicles for each route. This will change the hour capacity per route, link and bus stop and will also affect the average headway. It has therefore a large effect on the evaluation index for passengers, but it is also important for operators. The amount of vehicles will affect employment in the sector, but will also define whether the operation of certain routes will be profitable for operators and whether overcrowding or overcapacity will occur. It is therefore important for the government to keep track of these figures, which is not happening in the current planning system.

Calculation

The total amount of vehicles in the system is a simple sum of all vehicles on all routes. There are three vehicle types that have a predefined amount of seats for passengers.

Each vehicle typically has two employees, a driver and a fare collector. The total amount of employees to operate the vehicle park is therefore also a simple calculation of all vehicles multiplied by two. This does not incorporate the employees that are required for maintenance, security and office tasks. There is no data currently available on the size of this employment pool, so the final amount of employees per vehicle is left to the end-user to define in a later stage.

Presentation

The amount of vehicles per type is presented best in a chart. When required, this could also be presented on a map, depicting the total amount of vehicles or the amount of vehicles per type on a route or link. The total amount of employees in the public transport sector is also best presented in a chart, to be able to track differences in total employment between various scenarios.

Limitations

This simple calculation does not distinguish between privately owned or company owned vehicles, which would be an important point of interest in vehicle park reforms. This is however currently not documented well and therefore does not allow for further research. It also does not have an important spatial component, so rationalization of this ownership structure should focus more on regulatory reforms.

Implementation

The setting of the amount of vehicles per bus route is already mentioned in an earlier section and is therefore not repeated here. The amount of employees per vehicle can however be set by the end-user. Its standard value is 2, as all vehicles have a driver and a fare-collector. Especially larger operators however employ ground-staff at the terminals, which would change the average number of employees per vehicle. This can therefore be set by the end-user with the assumptions shown in Figure 28.

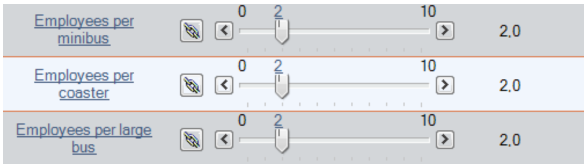

Figure 28: Assumptions for number of employees per vehicle type

The indicators for total vehicle park and size of the employment pool are presented in the charts shown in Figure 29 and Figure 30. When the underlying assumptions are changed, as a result of this the indicator values will also change. This is then shown in the charts in a shaded area, depicting the growth or reduction of the vehicle park and employment pool.

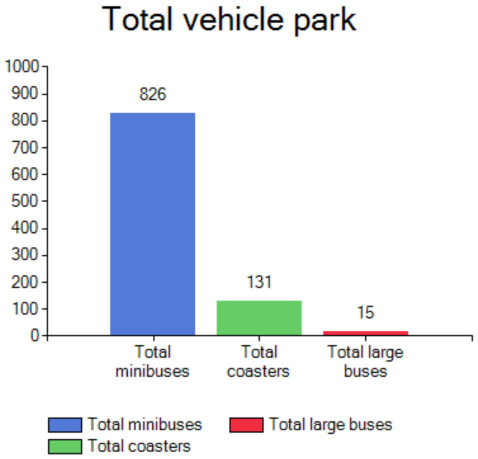

Figure 29: Vehicle park size indicator chart

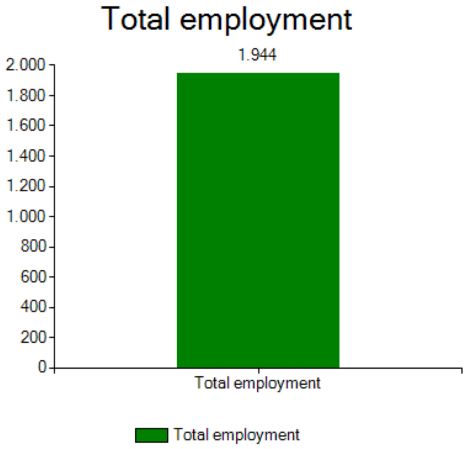

Figure 30: Employment indicator chart

4.4.2.8 *Fare prices*

Definition

The fare price structure in Rwanda is based on a large set of assumptions that is generalized for the whole country. It aims to calculate a fare price per kilometre based on the average cost price with a profit margin for operators. This fare price per kilometre is currently set at 19 RWF (Rwandese Francs) per kilometre, which is aggregated into a flat fare price per bus route.

The calculation of this fare price is revised regularly in stakeholder meetings. This is however often done based on the stakes of operators and government, without a clear picture of the consequences for passengers. In this PSS, the complete fare price calculation is implemented with variable parameters, which allows for extensive experimenting with the values of parameters to come to a good fare price. The fare prices per route are presented to the user, to be able to judge which routes would be affected most by rising prices. When compared with the income per sector in the affordability indicator, the fairness of these prices for passengers can be determined.

Calculation

The calculation of the fare price per kilometre is derived from the fare price calculations that are proposed by RURA (source unpublished). They consist of the elements in Table 5, that are combined to form the cost price and, including profit, the fare price.

Cost price elements
Fuel costs (based on fuel prices and average trip distance)
Number of passengers moved (based on seats in a coaster and average number of trips per day)
Depreciation of average vehicle (coaster)
Insurance costs
Tax costs
Driver salary
Inspection costs
Employee (fare collector) salary
Parking fees
Cleaning fees
Maintenance fees
Communication costs
Security costs
Office costs
Tire replacement costs
Bank profit (interest on loans)
Operator profit

Table 5: Elements of the fare price calculation

Because some policy makers would not be interested in the exact calculation of the fare price per kilometre but are more concerned with the effects of a certain price, the fare price can also be set directly by the user of the PSS. This allows for accessibility of the system for users that are not familiar with cost price calculations.

Presentation

The fare price per kilometre is presented in a chart, which mainly gives an idea of the price fluctuations that occur when cost price parameters are changed. An overview of all parameter values can be presented in a report generated by CommunityViz. A policy maker might also be interested in the total fare prices per route, which can be presented in a map view or report output.

Limitations

The fare price calculations are currently not linked to the actual operation in the network in the PSS (like the definition of the average vehicle and the number of trips and passengers), because this would not benefit the clearness and intelligibility of the calculations. This can however be connected in the future to help policy makers to get a better understanding of cost price structures in reality, which would benefit the decision making process.

Implementation

The cost price elements mentioned above are all implemented as end-user configurable assumptions, shown in Figure 31.

Figure 31: Assumptions defining the fare price per kilometre

They determine the cost price per kilometre, which is shown in a chart in Figure 32.

Figure 32: Fare price indicator chart

For end-users that are not interested in the disaggregated development of this fare price, the fare price per kilometre can be set manually, as already mentioned in section 4.4.2.1.

The theoretical fare per route is set based on the rules described above, as a product of the fare price per kilometre and the length of the route (one way). It is however common in Rwanda to make adjustments to this fare manually for otherwise non-profitable routes, for example because of low demand, bad road conditions or hilly terrain. The theoretical fare is therefore almost never the actual chargeable fare.

The fare prices per route can therefore be further determined by the end-user of the PSS, by the availability of a scaling factor for the fare of each route. These can be set with assumptions, a few of which are shown in Figure 33. These are set to 100% by default, and can be used to rationally make the fare prices higher or lower based on arguments of stakeholders and the effects on for example affordability.

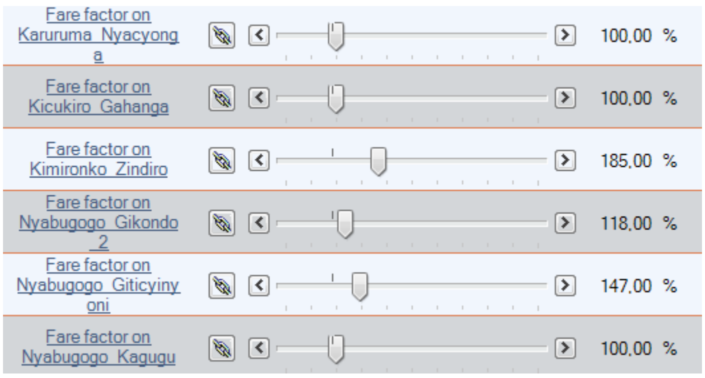

Figure 33: Assumptions determining the fare price scaling factors

4.4.2.9 Financial consequences

Definition

The financial consequences of changes in the vehicle park (especially the purchasing of new vehicles) are taken by the individual operators, whether they are private operators or larger companies or collectives. Because these consequences are however also interesting information for policy makers, who are responsible for putting this burden onto the operators when enforcing changes in the vehicle park, financial investments are also incorporated in the PSS. Policy makers can review the capital investment costs that are the results of their policies, to consider if these costs are feasible. A threshold of maximum allowable investment costs could be set to limit the burden laid on operators.

The inclusion of financial consequences also makes the PSS interesting to work with for operators, who can review the effects of policies presented by the government and discuss this in stakeholder meetings.

Calculation

The financial consequences of the policy are calculated by multiplying the costs of extra vehicles by their cost price. The amount of extra vehicles per type that is needed is calculated by comparing the existing vehicle park with the required vehicle park after implementation of a policy. The investment costs per vehicle type can be set interactively by the user. A threshold can be set, to give an alert when the total investment costs exceed a certain budget. This can help to keep the financial consequences of policies within limits.

Presentation

The total investment costs are presented as a single value in a chart. This does not distinguish between different operators, but gives an indication of the total investment costs of the policy.

Limitations

The actual costs of introducing a policy are of course very different than the presented indicator. Old vehicles could be scrapped, which costs money, or can be sold, which would reduce costs. Changing vehicle types would also require investments in parking space, terminals and other costs not directly linked to the vehicle. There is currently no information available to implement these costs in the PSS, but in cooperation with operators, this indicator could be extended to incorporate all costs.

Other policy changes, like the extension of routes or the replacement of bus stops, would also cost money. These are often direct costs for the government and should therefore also be presented as investment costs in an indicator. Unfortunately there are currently no estimations available about the size of these costs, so they cannot be implemented in the PSS. When more information becomes available, this indicator can be extended to give a clear understanding of the total costs for society.

Implementation

The total size of the vehicle park that was calculated in section 4.4.2.7 is compared with the size of the vehicle park before the policy. To allow for full operability, these values can be set by the end-user. He can also set the investment costs for buying a new vehicle of each type, as can be seen in Figure 34.

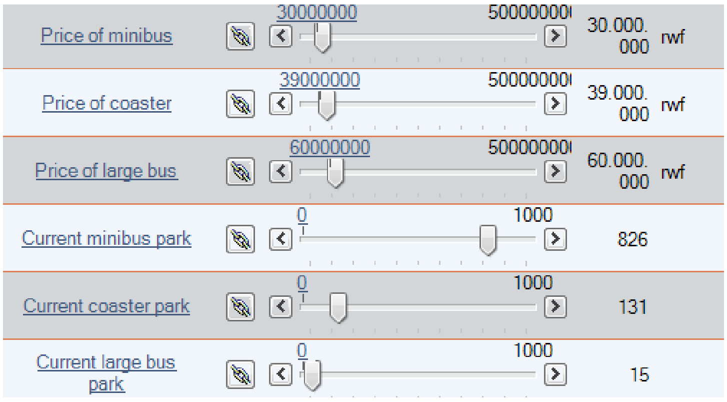

Figure 34: Assumptions for calculation of investment costs

The final investment costs are presented in a chart. As the value of the investments is dependent on the policies selected in a scenario and is set to zero in the base scenario, this chart is not displayed here.

4.5 Limitations of the PSS

The limitations of this prototype PSS can be distinguished in two different types: the limitations of a PSS in general and the limitations of this prototype in the considered context. The most important limitations of both types will be mentioned in this section, based on literature research and the limitations already encountered earlier in this chapter

4.5.1 Limitations of a PSS in general

The limitations of a PSS when compared with a transport microsimulation model were already discussed in section 2.2.2. The lack of detail in the modelling in PSS analysis is the main drawback of using such a system. PSS calculations are mainly based on simple cause-effect calculations with available data, while microsimulation models tend to use detailed datasets to produce stochastic predictions.

An example of such a prediction that can only be modelled realistically using on stochastic modelling is the implementation of behavioural effects of travellers. Part of the decisions of travellers can be assumed to be based on rational decision-making, but a lot of their choices are made based on external factors or arbitrariness. Because a PSS usually uses cause-effect calculations for choice behaviour, this unpredictable behaviour is not accounted for. The uncertainty is enlarged by the effects of elasticity of for example price and delay. This elasticity might be different for all persons, resulting in unexpected behaviour.

Due to the mentioned relative lack of detail and ability to account for uncertainty in the PSS model, policy makers cannot fully lean on the results of this model when implementing policies. They can however use the PSS very well for more coarse analysis and reference, which preserves the reason for existence of PSS models in the public transport planning practice, especially in the context of Rwanda, where reliable datasets and detailed models are scarce.

4.5.2 Limitations of this prototype

In this prototype PSS, a few indicators were selected to be implemented. The choice for these indicators was based both on literature research and on the requirements selected from the field study. The possibility to implement these indicators however also relied heavily on the availability of data. This lack of data, which especially originates from the decentralized collection and application of datasets, limits the abilities of this prototype to fully represent reality.

As is clear from the rest of this chapter, the PSS model does not incorporate feedback mechanisms that represent passenger behaviour, like for example elasticity on price or delay. Other limitations mentioned in earlier sections were the absence of detailed passenger routing (bus stop and vehicle selection, transfers), congestion, pre-transport distances and the actual intensities of buses. Indicators describing operator and government finances like the calculation of cost prices and the actual costs of policy implementation are also not modelled in detail.

The major drawback of the inability to represent passenger behaviour lies in the need for policies to be implemented. Most indicators presented the previous section and policy examples in the next section are favouring passengers. Because the PSS is not able to show the positive effects this might have on passenger demand or travel behaviour, a strong external motivation should be present to make implement these policies. The successful implementation of the PSS in the planning and policy making practice would therefore be favoured by a strong effort to incorporate this feedback into passenger behaviour.

Most of the limitations mentioned above are direct results of the lack of data. The open structure of the PSS however allows for future implementation of better indicators, when more detailed data becomes available. The use of this PSS will probably encourage more structured collection of data, which would strengthen this process. The limitations of this prototype can therefore be overcome by a wilful implementation and future effort to further expand its capabilities.

4.6 Scenario development and evaluation

The assumptions described in this report can be combined into scenarios, which represent plans and policy proposals. Five of these proposals and their implementation in the PSS are described below as an example. These are the following scenarios:

- Actual fare pricing scenario
- Passenger oriented fare pricing scenario
- Vehicle park restructuring scenario
- Vehicle park replacement scenario
- A combination scenario of a fare pricing and vehicle park scenario

They are based around the two central policy themes of fare price determination and vehicle park configuration. The scenarios are not all directly based on actual policies, but they are used to show the evaluation possibilities of the PSS and to strengthen the recommendations for rationalization in the next section. For all scenarios, the AMPH traffic period is reviewed.

4.6.1 Actual fare pricing scenario

The practice of assigning scaling factors to the fare prices on most routes is based on discussion between stakeholders and their knowledge and experience in the field. It is important to make the effect of these scaling factors clear and help to determine their value in a fair way. The PSS therefore offers a rationalization-for-decision-making approach for determination of route fares.

In this scenario, the theoretical fare prices (at a fare rate of 19 RWF per kilometre) and the actual current charged prices are compared. This required the calibration of these prices through the fare scaling factors. The actual prices used were based on a fare determination scheme retrieved from RURA, which has also served as the base for the kilometre fare determination calculations. This practice of determining and scaling prices can be further rationalized by the PSS in the future.

The scaling factors applied are visible in Figure 35. For the routes where it was not clear what the current fare is (due to missing data), the real fare is set to the theoretical fare (factor 100%).

Name	Units	Base Scenario	Real prices
Fare factor on City_Gikondo_1	%	100	117
Fare factor on City_Gisozi	%	100	102
Fare factor on City_Kacyiru	%	100	127
Fare factor on City_Kagugu	%	100	160
Fare factor on City_Kicukiro_1	%	100	134
Fare factor on City_Kimironko	%	100	87
Fare factor on City_Kinyinya	%	100	83
Fare factor on City_Nyabugogo	%	100	100
Fare factor on City_Nyamirambo_I	%	100	112
Fare factor on City_Remera	%	100	105
Fare factor on Continu	%	100	100
Fare factor on Karuruma_Nyacyonga	%	100	100
Fare factor on Kicukiro_Gahanga	%	100	100
Fare factor on Kimironko_Zindiro	%	100	185
Fare factor on Nyabugogo_Gikondo_2	%	100	118
Fare factor on Nyabugogo_Giticyinyoni	%	100	147
Fare factor on Nyabugogo_Kagugu	%	100	100
Fare factor on Nyabugogo_Karuruma	%	100	117
Fare factor on Nyabugogo_Kicukiro_2	%	100	100
Fare factor on Nyabugogo_Kimironko	%	100	71
Fare factor on Nyabugogo_Nyamirambo	%	100	109
Fare factor on Nyabugogo_Remera_I	%	100	86
Fare factor on Nyabugogo_Remera_II	%	100	86
Fare factor on Nyamirambo_butamwa	%	100	100
Fare factor on Remera_Gikondo	%	100	143
Fare factor on Remera_Kabuga	%	100	73
Fare factor on Remera_Kanombe	%	100	84
Fare factor on Remera_Kicukiro	%	100	100
Fare factor on Remera_Masaka	%	100	81
Fare factor on Remera_Rubirizi	%	100	117
Fare factor on ULK_Kagugu	%	100	100

Figure 35: Fare scaling factors for the actual fare pricing practice scenario

The total aggregated affordability in the system is only effected by 0.01 (1%), which is shown in the score comparison in Figure 36. The other index scores remain the same.

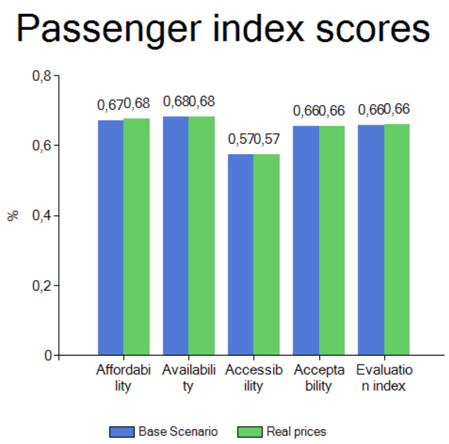

Figure 36: Passenger index scores for base scenario and “actual fare pricing” scenario

This has no major implications for the affordability in most areas, as can be seen in the map scenario comparison that is shown in Figure 37. The map scenario comparison tool in CommunityViz enables the user to easily compare the spatial effects of policies. A screen capture of this tool is presented for all scenarios in this section, to represent the overview that the end-user has while using the PSS.

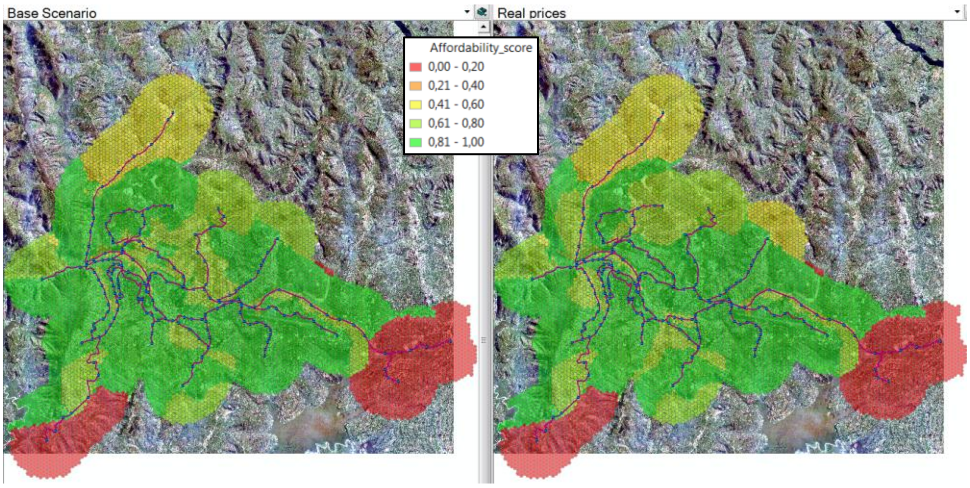

Figure 37: Scenario comparison of base scenario and "actual fare pricing" scenario

The fare scaling policy of the government, that mainly serves the interests of operators, therefore do not seem to affect passengers much. There are however areas that would be served by more passenger oriented fare pricing policies.

4.6.2 Passenger oriented fare pricing scenario

The introduction of a passenger oriented fare pricing policy, based on data about the effects of price changes, contributes to a rationalization-for-efficiency process. One of the pricing policies the government could develop, is to aim for affordable public transport for all inhabitants of Kigali. Areas of interest for these policies can be found by looking at the affordability scores and their corresponding bus routes.

This is done in this scenario by further elaborating on the actual fare pricing scenario described in the previous section, where areas with very low affordability scores can be clearly defined. Some fare scaling factors are adjusted (Figure 38) to test the effect on affordability in all areas (Figure 39). The effects on overall affordability and the total passenger index are obvious and clear.

Name	Units	Real prices	Price strategy
Fare factor on Karuruma_Nyacyonga	%	100	80
Fare factor on Kimironko_Zindiro	%	185	150
Fare factor on Nyabugogo_Giticyinyoni	%	147	125
Fare factor on Nyamirambo_butamwa	%	100	70
Fare factor on Remera_Kabuga	%	73	60
Fare factor on Remera_Masaka	%	81	70

Figure 38: Fare scaling factors for the "passenger oriented fare pricing" scenario

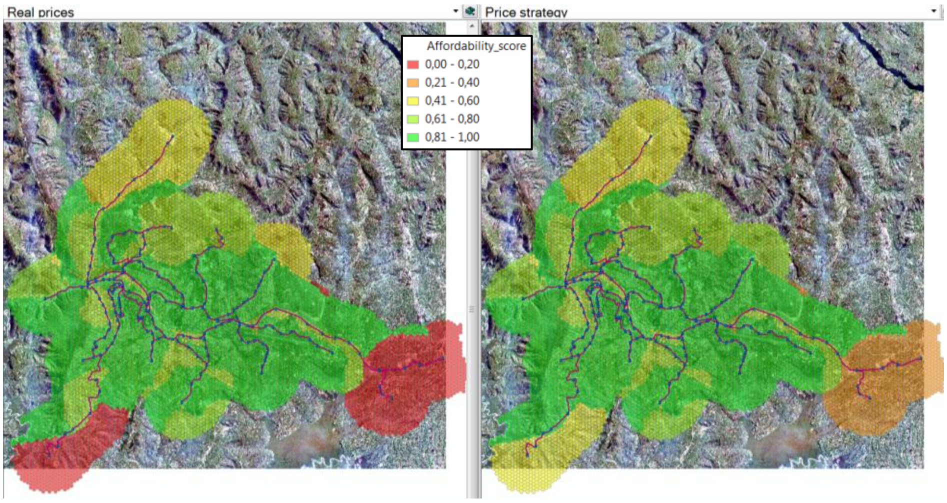

Figure 39: Scenario comparison of "actual fare pricing" scenario and "passenger oriented fare pricing" scenario

The fare reductions will favour the financial position of passengers, but could at the same time frustrate the operators on these routes, as they will lose profit. Such a policy should therefore be strengthened with a profit distribution policy, for example in which the operators on more profitable routes pay more taxes, which are in turn paid back to the operators on less profitable routes by tax reduction. To be able to define this distribution and reallocation in the PSS, more data about the actual profits of all operators is required. Together with representatives from the government and from all operator companies and cooperations, profitability data can be implemented in this PSS to be able to define correct reallocation measures.

4.6.3 Vehicle park restructuring scenario

When looking at the base scenario in terms of availability (time headways throughout the network), acceptability (capacity available at a location) and demand satisfaction (hour link capacity compared with assigned demand), it becomes clear that the current configuration of buses on the network is not optimal. This is probably because of the tendency of operators to operate on the busiest and longest routes, which in theory are more profitable. Some other routes are however heavily underserved, which is negative for the passengers on this route. This underservice also implies possible profitable operation on these routes, which could make operators shift their practice. This asks for a rationalization-for-efficiency approach, in which the currently available resources are distributed in a more efficient way. No new vehicles are introduced in the system in this scenario, but currently operating vehicles are redistributed over the system.

In the policy described in this scenario, the government can take a leading role by assigning quota to the issuing of route licenses. This will shift operators towards other routes, until some optimum is reached. This simple scenario (consisting of the assumptions in Figure 40), as an example of such a shift, is based in this scenario on demand satisfaction and availability (time headways), as can be seen in the map comparison (Figure 41). The scenario has positive effects on both availability and acceptability (Figure 42).

Name	Base Scenario	Vehicle park restructuring
Minibuses on Remera_Masaka	7	15
Minibuses on Remera-Rubirizi	4	17
Minibuses on Remera_Kicukiro	23	16
Minibuses on Remera_Kanombe	11	18
Minibuses on Remera_Kabuga	75	60
Minibuses on Nyamirambo_butamwa	10	18
Minibuses on Nyabugogo_Kimironko	100	88
Minibuses on Nyabugogo_Karuruma	56	48
Minibuses on Nyabugogo_Giticyinyoni	4	6
Minibuses on Nyabugogo_Gikondo_2	30	25
Minibuses on Karuruma_Nyacyonga	16	12
Minibuses on Continu	4	10
Minibuses on City_Nyamirambo_I	100	86
Minibuses on City_Nyabugogo	17	32
Minibuses on City_Gisozi	10	16
Coasters on City_Remera	54	40
Coasters on Nyabugogo_Remera_II	0	14
Large buses on Continu	5	9
Large buses on City_Remera	4	0

Figure 40: Vehicle park assumptions in the "vehicle park restructuring" scenario

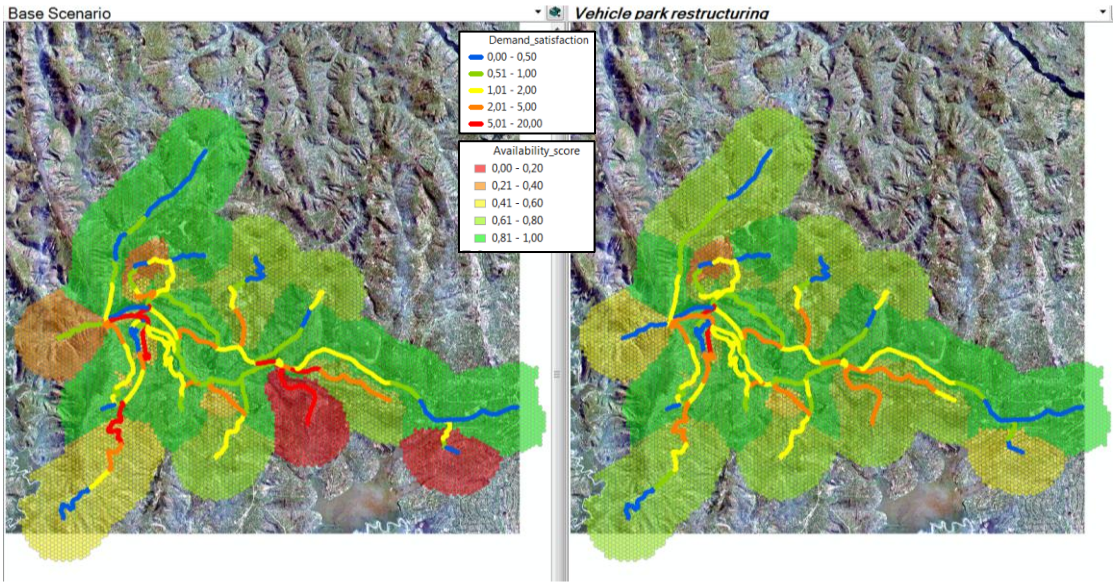

Figure 41: Scenario comparison of base scenario and "vehicle park restructuring" scenario

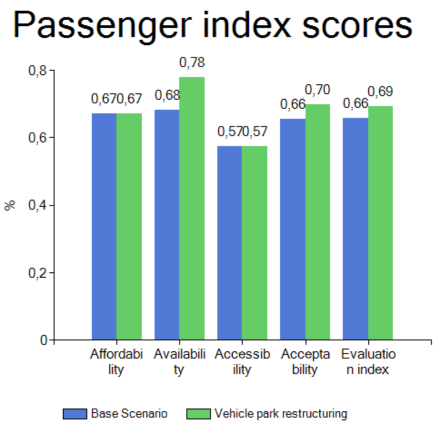

Figure 42: Passenger index scores for base scenario and "vehicle park restructuring" scenario

It is clear from Figure 41 that the demand satisfaction in the whole system is improved for both passengers and operators, as fewer routes have overcapacity (blue) while most routes with too little capacity (red) are better served. At the same time, the time headways in the whole system have decreased (which is also clearly visible in Figure 42), resulting in a better service situation at the same costs (as no extra vehicles were introduced in the system).

4.6.4 Vehicle park replacement

An important aim in the rationalization policies of the Rwandan government is the replacement of minibuses with larger vehicles, following their rationalization-for-formalization vision. Checking the effect of these measures in PSS scenarios is an important step before implementing such a policy or issuing a further investigation. This reduces the chance of making rash formalization decisions and rationalizes policy proposals, which leads to more effective implementation.

In this scenario, the "vehicle park restructuring" scenario is further elaborated on, by replacing minibuses on certain routes in pairs of three by large buses (as their capacity difference is around a factor three).

Two sub-scenarios are reviewed:

- The complete replacement of all minibuses with large buses (by completely limiting the issuing or extension of minibus licenses)
- Partial replacement of minibuses with larger buses on the busiest links

The assumptions for the first scenario are clear: all minibuses are replaced by larger buses, while the coasters are kept at the same number. This has significant negative effects on the average availability score in the system (Figure 43), due to the large increase of time headways and waiting times. This is especially the case in the suburbs of Kigali (Figure 44), where average waiting times are already longer because of the lower route density. While remaining at about the same capacity level, the public transport system has therefore lost a lot of its quality for passengers.

The second scenario only replaces part of the minibuses on some of the busiest routes. The minibus vehicle park shrinks with more than 40% due to this policy (Figure 46), while global index scores (Figure 43) remain unchanged and there is also no negative effect on local scale (Figure 45). This shows that a partial, targeted replacement of vehicles has significantly less negative effects on quality of the system for passengers.

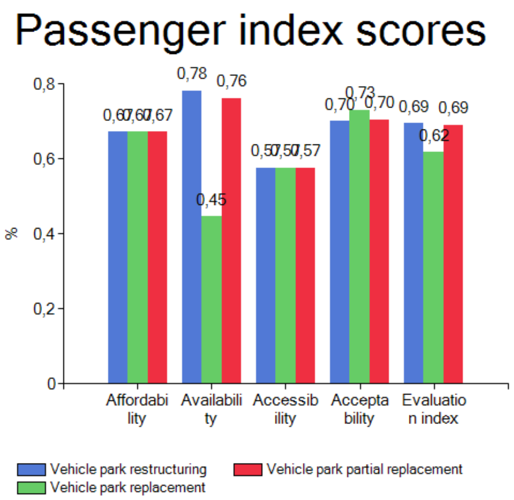

Figure 43: Passenger index scores for vehicle replacement scenarios

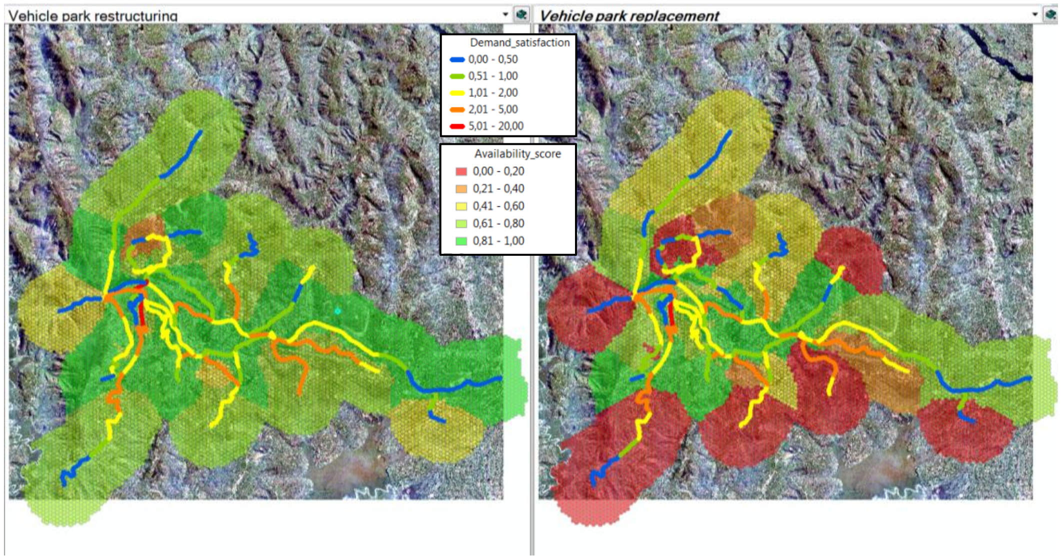

Figure 44: Scenario comparison of "vehicle park restructuring" and "vehicle park replacement (complete)" scenario

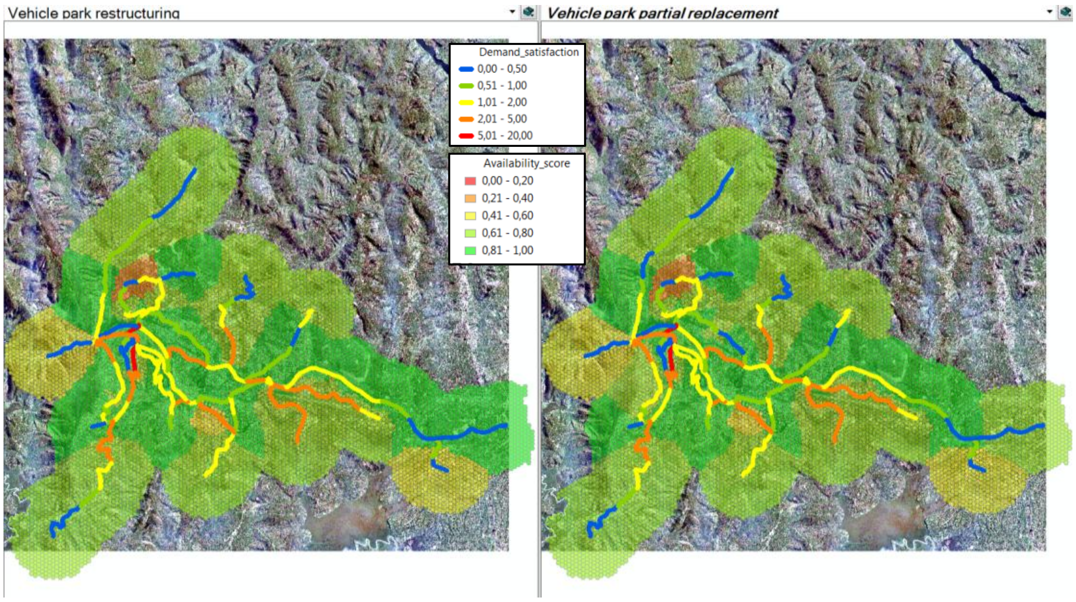

Figure 45: Scenario comparison of "vehicle park restructuring" and "vehicle park replacement (partial)" scenario

The effects of both sub-scenarios on the investment costs for this policy and the total employment are also very different. While the first scenario decreases employment with more than 50% and implies investment costs of more than 16 billion RWF, this effect is much less for the partial replacement scenario (Figure 46). This is an obvious result as costs and employment are linked to vehicle park size, but it should be kept in mind that investment costs and the loss of employment should be compensated, which would partly be reflected into the fare price in reality. Too large a change would have a large effect on affordability and possibly even on demand, which would further decrease the quality of the system. Gradual and targeted policies, like the one proposed above, are therefore most of the time more desirable.

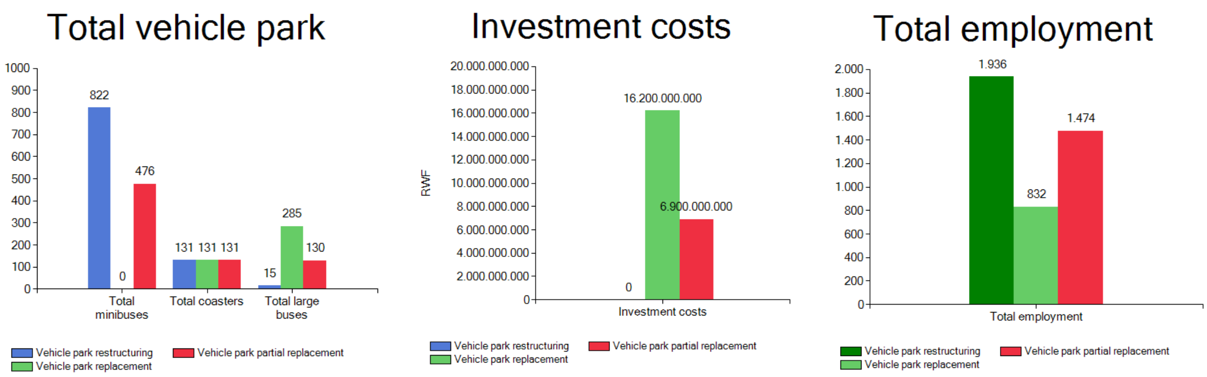

Figure 46: Vehicle park size, investment and employment figures for vehicle replacement scenarios

4.6.5 Combination scenario

The two most rationalized scenarios described above, which are the passenger oriented fare pricing and vehicle park partial replacement scenarios, are combined in a combination scenario. No extra parameter calibration was done, but this scenario only shows the ability of combined policy packs to improve the overall quality of the system for passengers.

As can be seen in the chart in Figure 47, the average evaluation index score is improved due to the improvement of the other individual scores. This has also happened on a disaggregated scale, as seen in the map comparison in Figure 48. Accessibility has not been changed in either of the scenarios and is clearly the most important point of interest for further improvement of this scenario.

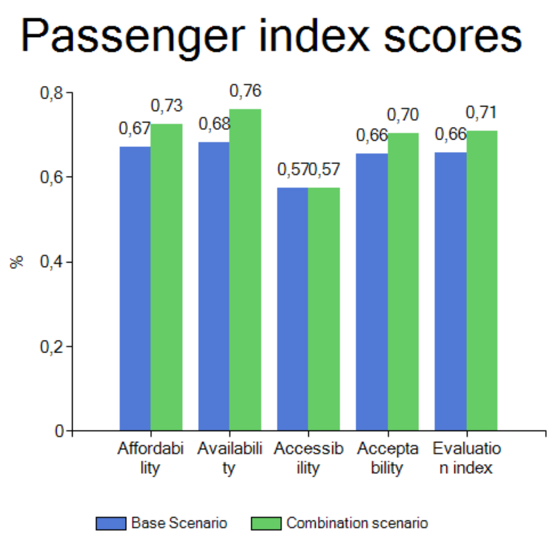

Figure 47: Passenger evaluation index scores for base scenario and combination scenario

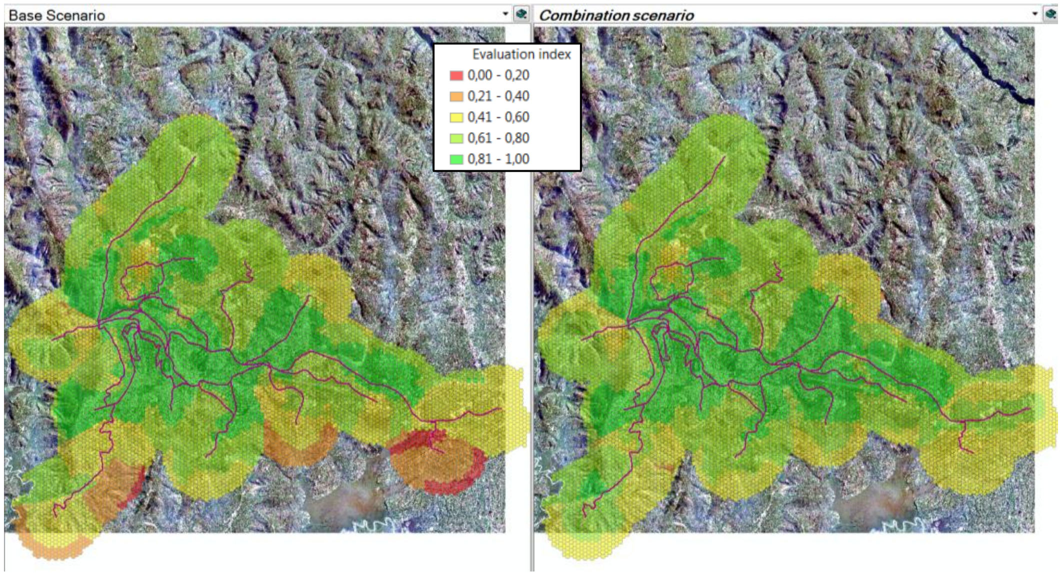

Figure 48: Scenario comparison of base scenario and combination scenario

4.6.6 Other scenarios

Because of the interactive nature of the PSS, an almost infinite number of scenario combinations is possible. Other interesting scenarios that are possible to generate with the current configuration of the PSS, but that are not described in this report are:

- Reconfiguration of the bus stop locations (to improve accessibility)
- Changing the regulations on maximum waiting times (to improve either availability or operator profitability)
- Changing the average speeds in the network (to include the effect of priority measures)
- Determining a fair and affordable fare price per kilometre by changing cost price parameters
- Proposing variable vehicle park configurations for different traffic periods

More scenario options could become available with the addition of extra indicators, based on new data sets or calibration. This is further elaborated on in the recommendations of this report.

Rationalization of planning

5 Rationalization of planning

The PSS described in the previous chapter can be applied in the planning practice in Rwanda, in which it can help to rationalize this process. This chapter will describe the possible use of the PSS for rationalization and will give some recommendations for rationalization based on the experiences during the field work.

Chapter outline

The application of the PSS for working on a rationalization vision is described in the first section of this chapter, while recalling the definitions of rationalization from Chapter 2 and the lessons learned from the field study and the development of the PSS. In section 5.2, this is operationalized in a rationalization vision, in which recommendations for rationalization are presented. These recommendations form a draft rationalization plan, which could be used to lead the discussion about rationalization of public transport in Rwanda.

5.1 Application of Planning Support System in rationalization process

The PSS developed in this research can be used by all users mentioned in chapter 4.1 to rationalize their planning and decision making process. The use of the system can lead to policy proposals that are based on clear targets and are more easily supported by other stakeholders and the public. Policies substantiated with PSS figures are likely to reduce the opposition against them and will encourage the cooperation of all stakeholders. All three definitions of rationalization described in chapter 2.1 are supported by the use of a PSS, as was already mentioned in chapter 4.6.

5.1.1 Rationalization-for-formalization

The formalization process that is currently in progress in Rwanda can be guided by the PSS in making clear what the characteristics of the current vehicle park and employment situation are and what their effect is on the quality of the system. Formalization of the public transport system will start with introducing extra regulations for operators, which will lead to fusions of operators in larger cooperatives or companies. Because this makes operators less vulnerable to requirements imposed on their vehicle park, the government can further formalize the system by requiring minimum vehicle sizes on certain routes. On the long term, this might lead to the phasing out of undesirable vehicle types like minibuses, as is one of the current formalization visions of the Rwandan government.

The PSS can help figure out what the results of these policies would be for the adequacy of the network for passengers and the investment costs for operators. This can lead to conclusions about the desirability of certain formalization policies and can point out opportunities for optimization of the current resources. An example of such a policy evaluation was given in chapter 4.6.

5.1.2 Rationalization-for-efficiency

Making the public transport system more efficient is often an important goal of rationalization and should therefore be a main focus for planning support. In the developed PSS, policy makers can combine demographic information (like population figures and average income), travel information (trip production and attraction per zone) and public transport supply characteristics (location of bus stops, capacity per link). These combined figures can point out areas that cope with inefficient public transport. This could mean that an area is underserved by public transport, but also that there is overcapacity. These inefficiencies make the system costly and unpleasant to travel with and have to be rationalized to reach higher private and social returns.

After these areas of interest are pinpointed, the user of the PSS can implement several scenarios that reallocate resources through the network. These scenarios can be compared with each other to find solutions that are more efficient on a local and global system scale, without the need to introduce extra resources.

The PSS allows for flexible use of weighing factors that can be adjusted to fit the intentions and policy targets of the user. In this way, multiple stakeholders can each implement their own scenarios and weights of indicators, to help them negotiate for their stakes in policy making meetings and come to efficiency increasing policies.

5.1.3 Rationalization-for-decision-making

The decision-making process in Rwanda currently often seems to be based on rhetoric and personal experience of the decision makers. This is sometimes supported by datasets available at some of the stakeholder institutions or reports provided by external parties, like consultancy companies.

The use of the developed PSS could help rationalize and standardise this decision-making process. All stakeholders participating in decision-making meetings could surrender their data for implementation in the PSS, which would make it possible to base all policies on the same data and to make decisions based on measurable effects of policy scenarios. Because the final decisions can be presented in a rational and reliable way to all stakeholders, this will encourage collaboration and agreement.

The PSS further allows for participation of all stakeholders in the various steps of the design model, from the identification problems to the design and assessment of alternatives. This could even lead to the use of the PSS in community participation meetings, to facilitate the intention of the government to involve civilians in this design model.

5.2 Recommendations for rationalization

During the development of the PSS in this research, some observations were done that can be valuable recommendations for rationalization of the public transport system in Kigali. These observations were found in literature about public transport rationalization, during the field work in Kigali and during the inspection of all datasets in the PSS. The most relevant recommendations for rationalization will be elaborated on below. They will not form a complete rationalization framework, but they can be leading for further research in the PSS and discussion about public transport rationalization in Rwanda.

5.2.1 Regulation of vehicle movements

One of the parameters introduced in the PSS is the ability to set maximum waiting times of buses at bus stops and terminals. The introduction and adequate enforcement of these regulations would be an important first step to get a better grip on the public transport system and to rationalize it in the sense of rationalization-for-formalization. This would allow for adequate representation of the system in data used for planning and policy making, as this representation is currently not reliable due to the unpredictable behaviour of most operators. The regulation of waiting times would however also decrease the headways of vehicles and reduce the chance that people are left at bus stops because vehicles are full.

This rationalization-for-formalization could be further increased by doing a serious effort to regulate the amount of vehicles per route, by targeting the issuing of licenses based on demand data and passenger evaluation indicators. Not only would this decrease the informality of the system, it would also allow planners to guide the system towards better efficiency and rational decision making.

5.2.2 Restructuring of the vehicle park

One of the most frequently mentioned measures, both in literature and in the field study, is the replacement of the minibuses in the current vehicle park with larger buses. A replacement policy is already in progress, by not issuing licenses to new operators with minibuses anymore. This is however only a partial solution as existing minibus operators are still allowed to extend their licenses.

Replacing all minibuses with large buses however does not seem to be the perfect short-term solution for the problems signalled in Kigali. Each large bus would replace the capacity of around 3 minibuses and would therefore decrease employment in the sector heavily. Because fewer vehicles will be used to serve the same demand, the time headways and therefore the waiting times will increase significantly. Besides that, while large buses might be polluting less per passenger and creating less congestion, they have more trouble to climb the hilly roads of Kigali and navigate through congestion, which reduces these effects partly. When confronted with the maximum waiting times at stops, they might not be more profitable either than minibuses.

The vehicle park transition process should therefore be continued, but only with a rational replacement program in place. This program can be developed with the use of the PSS and should be based on rational decision-making with operation data and data about the vehicle park. Policy ambitions that point out the minimum and maximum amount of vehicles to be replaced should be developed and tested in the PSS. Several scenarios could be tested, in which vehicles are for example replaced directly while keeping the same service level on all routes or in which the current vehicle park is shifted differently to create better efficiency.

It is clear from the PSS that replacing all minibuses with large buses will both decrease employment in the sector and put a high investment burden on operators. The focus of rationalization of the vehicle park should therefore lie on shifting minibuses to the peripheral routes and only introducing larger buses on the busy main routes. Other possible indicators that could support this decision would be the geographical configuration of the city and the distribution of demand. An optimum configuration of the vehicle park, based on clear policy ambitions, can be developed by all stakeholders together with use of the PSS.

5.2.3 Institutional reforms

The discussion to introduce a public transport authority, overarching all planning and policy making around public transport, has already been conducted in Rwanda for some time already. It has not been successful however, because of the fragmented public transport sector that is placed under several institutions. These institutions are therefore currently only cooperating in policy making meetings, in which individual policies are tuned with each other. The PSS developed in this research tries to accommodate this situation, but it would be better to work towards an authority or organization that can aggregate the practices of all these different institutions. Such an organization should structure and rationalize the following practices:

- Initiation and structuring of planning and policy making meetings
- Allocation of planning and policy making tasks
- Matching and connecting policies of various institutions
- Collection of all relevant data and knowledge about the public transport system
- Management and further development of the PSS

This organization could for example be presided by MININFRA and should have good contacts with representatives of all major planning and policy making institutions. It should not be possible to execute policies aiming at public transport without intervention of this organization, to be able to put a halt to the current policy sprawl.

5.2.4 Cooperation for fare collection and distribution

Although the formalization and increase of efficiency of the system might lead to operational benefits on a system level, they might lead to financial losses for individual operators. These are currently often operating privately and use the freedom of the informal system to maximize their personal revenues. These operators will therefore not be eager to cooperate in the rationalization of routes and the vehicle park, as they will lose revenues or even become unemployed.

The rationalization-for-formalization and -efficiency should therefore be preceded by an institutional reform on the side of operators. This has already been started some time ago in Kigali, where some institutions encourage operators to organize themselves in cooperatives or start working for larger companies. When this is enforced on the short term, these larger operators can be forced to adopt structures for fare collection and distribution.

Currently, the maximum fare prices per kilometre and route are defined in a way that tends towards rationalization-for-decision-making. The policy making institutions could rationalize the fare collection further by introducing a reliable ticketing system. When adequately introduced, this can allow for the redistribution of money between all operators. Profit redistribution would make it possible for individual operators to continue service on less profitable routes. Another benefit of this method would be the ability to sell transfer tickets that allow people to use multiple buses on their route, without paying the complete route fares.

Introduction of such a system should happen in the light of rationalization-for-efficiency and rationalization-for-decision-making, as it should not lead to large financial loses. The revenues per route and the profits per operator should be recorded and compared, to be able to eliminate financial inefficiencies that are unnecessary.

5.2.5 Data-driven decision making

As already mentioned in section 5.2.3, a central organization should be created that is concerned with the collection of data and knowledge from all institutions that are connected to the public transport system. Next to the collection of explicit datasets, the organization should also try to collect as much tacit knowledge from these institutions. The collection of as much data as possible in the PSS will lead to more rational decision-making, as it will reduce the need for making assumptions.

The organization can act as a data bank for government institutions and consultants working on the public transport system and can make an inventory of data that is unavailable and should be collected. This data collection should happen in close collaboration with NSIR, departments of other ministries and external parties.

With a rationalized data collection scheme in place, the organization could be able to develop time series of for example demand data or traffic counts, which are important for the definition of growth scenarios. The public transport organization can also cooperate with other organizations working with for example land use data, to further increase the functionality of the PSS.

Conclusion and recommendations

6 Conclusion and recommendations

This chapter reflects on the research presented in this report. The research objectives set in chapter 1.3 are evaluated and consequences for the planning practice in Rwanda and the academic research on public transport rationalization and planning support systems are described.

The main research objective of this study can be divided in two parts: The *development of a Planning Support System* and the *rationalization of public transport planning in Kigali, Rwanda.* To reach this objective, the concept of public transport rationalization has been described in detail, followed by an analysis of the possibilities for rationalization of public transport planning in Kigali, Rwanda. A prototype PSS system has been developed to aid this rationalization, and some recommendations for the further use of this system in rational planning were given in the previous chapter.

Chapter outline

The first three sections of this concluding chapter describe conclusions on the main topics of this research. These are the concept of rationalization of public transport, the use of a PSS for public transport planning and the case study in Rwanda in which these two concepts were combined

Some recommendations for further possibilities and shortcomings of this research are mentioned in the next section and a comment on recent developments in the sector is made in the discussion in the last section.

6.1 Rationalization of public transport

The concept of rationalization is divided in three main definitions: rationalization-for-formalization, rationalization-for-efficiency and rationalization-for-decision-making.

The principle of rationalization-for-formalization describes the practice of turning an informal transport system into a formal system, by increasing regulations and requirements for operators and interfering in the system planning. Complete formalization is not always the best policy choice, because partial informality or flexibility of requirements is often also beneficial for the quality of the system. Rationalization-for-formalization therefore focuses on to what extent formalization is required and feasible.

Rationalization-for-efficiency is a way of restructuring the system while making use of existing resources, by allocating them towards parts of the system where they provide higher returns. These returns might be financial, but can as well include social equity benefits or other benefits prioritized by policy makers. A focus on rational planning rather than ad-hoc operation is the main target of this rationalization approach

Rationalization-for-decision-making mainly describes a rational way of planning and decision making. Rational decision making is ideally not only based on experience and tacit knowledge, but also on reliable datasets, measurable results and clear planning targets. All stakeholders are encouraged to share knowledge and data, to come to the best informed conclusions. Rationalization-for-decision-making is therefore a way of structuring this decision-making, which makes the policies that are the output of this process more trustworthy. This can facilitate the cooperation with multiple stakeholders and can increase the public support for policies.

These three definitions can be used by advising the Rwandan government to rationalize their public transport system and its planning. The wish to formalize the system should be honoured, but should be approach by a rational formalization and planning for efficient use of existing resources. To support governmental institutions in making these decisions in a rational way, a Planning Support System is proposed that can help cooperation with multiple stakeholders.

6.2 Planning Support System development

Planning Support Systems are best used in situations where a lot of stakeholders with comparable or conflicting stakes, interests, knowledge and data should work together effectively. This is the case in the public transport planning practice in Kigali, where multiple governmental and private organizations each have their own role in the development of the public transport system. In this research, a prototype PSS for Kigali is therefore developed and presented.

A PSS is a software system that gives planners the opportunity to visualize their proposals on a map and to assess them with indicators and scenario analysis tools. These proposals often have a spatial nature, but transport planning can also be supported by the use of a specific PSS. The main advantages of the use of PSS over traditional transport models are the following:

- PSS enables quick review of the expected global effects of policies without the need for expert input
- PSS makes the communication between technical planners and political policy makers more transparent and fluent, while transport models would make this conversation too technical.
- PSS is not as sensitive to data quality as a transport micro-simulation model.
- PSS systems are relatively affordable for users in a developing country.
- PSS is more applicable for decision making during meetings with various stakeholders and politicians than traditional transport models.

Main disadvantages of using a PSS, which were also encountered in the development of the prototype in this report, are the following:

- The coarse scale and focus on spatial elements
- The generalized results of the analysis
- The lack of behavioural modelling

The results of analysis in the PSS are therefore mainly valid on a global system scale and should be validated on a local scale with the use of traditional transport models. A PSS can point out areas of interest for this further analysis and can be used to present the final results of such detailed analysis.

The role of the PSS in Kigali will be to organize the available knowledge and data, to structure meetings between planning and policy-making stakeholders and to present the results of their proposals in a reliable way. It will require an attempt by all stakeholders to surrender their knowledge and data, which will in turn lead to better cooperation and more effective results.

Because the proposed PSS can be operated with basic GIS skills and with available software, it is very accessible for use by institutions in Rwanda. Another success factor for the PSS in Rwanda is probably that there is no minimum amount of data required and that all stakeholders can use the system in their own way. The system further allows for cooperation with multiple governmental organizations, but also for interaction with the public due to the clear visual presentation. When a good balance is found between complexity of the system and understanding for non-expert users, this can improve the communication between practical planners and visionary policy makers. Scenario studies in the PSS can be a good motivation for the issuing of more technical studies involving transport models and (micro) simulation.

Because of the focus in Kigali lies on restructuring the vehicle park and its operation and the configuration of bus routes and stops, these policies are mainly supported by the PSS. The end-users of the PSS in Kigali are split in three groups: The *planners* (practical and applied users), the *policy makers* (the visionary decision-makers) and *external parties* (which are interested in the data presented in the PSS or in cooperating with the other mentioned groups). The system should be able to comfort in the needs of all three user-groups.

The public transport system that the PSS is reviewing is also concerned with three groups of users. These are the *passengers*, the *operators* and the *government*. The latter is often the regulation providing institution, while the operators are the providers of the actual transport of which the passengers are the direct users. The representation of their stakes is the main focus in the indicators presented in this PSS, but there are also indicators that give important information to operators and the government. The indicators representing the stakes of passengers are based on the attributes Affordability, Availability, Accessibility and Acceptability. For each of these attributes, an indicator is chosen that is presented as a normalized score. All scores are summed in a general evaluation index, which can be used to define areas of interest for the improvement of public transport. Operators and government are served with indicators representing the size of the vehicle park, the total employment in the sector, the fare price and the total investment costs. This set of indicators can provide basic planning support, but can of course be supplemented by further research and availability of data.

6.3 Rationalization of public transport in Kigali City

Through enabling users to test policy proposals in a controlled environment, the rationalization approaches of rationalization-for-formalization, rationalization-for-efficiency and rationalization-for-decision-making are all supported by the use of the PSS.

The PSS makes clear what the characteristics of the current vehicle park and employment situation are and can help to further formalize the system by predicting the results of formalization policies for passengers and operators. It can also point out areas that are not adequately served by the system or routes that are not operating efficiently. The PSS allows for rational decision making in the stakeholder meetings that are set up for policy making in Kigali, which encourages participation of all institutions and the generation of consistent policies. It would therefore be very helpful for all aspects of the rationalization of public transport in Kigali.

The actual rationalization of public transport will have to be done by the planners and policy makers themselves. Besides the development of the PSS that can help them rationalize their own actions, this report has presented some recommendations for rationalization. These are in short the following:

- Regulation of vehicle movements by introducing maximum waiting times and regulating the amount of vehicles per route

- Restructuring of the vehicle park by reallocating vehicles through the network and gradually replacing minibuses with larger vehicles
- Institutional reforms, especially by introducing an overarching public transport authority that can structure and connect planning and policy making.
- Encouragement of cooperation of operators for fare collection and distribution, which enables the adequate operation of financially less profitable routes
- Introduction of data-driven decision making in public transport as the standard practice in public transport policy making

In all these rationalization practices, the PSS should be leading in the assessment of new policies, as this would make sure decisions are taken rationally and can be seen as such by other stakeholders and the public.

6.4 Recommendations

The PSS developed in this research is constructed with current data sets that are collected from policy making institutions in Rwanda. It is however probable that the PSS might not fit perfectly to the needs of all policy makers, due to the large proportion of tacit knowledge that is used for planning and policy making. The PSS should therefore be validated with all institutions, to be sure that they will support the outcomes. It would therefore be advisable to put the implementation of the PSS in the hands of one or multiple experts familiar with both transport planning and GIS. They can validate the system and calibrate the scenarios to fit reality and policy scenarios. On the long term, this task should be passed on to the public transport authority proposed in this research.

Extensive cooperation with public transport operators in the development of the PSS is important, because their knowledge and data is needed for good representation of new indicators. Their support of the PSS and its outcomes is also essential, as without the support of operators new policies will not have full effects. Cooperation with operators was unfortunately not possible in this research due to field study limitations, but should be a main focus in the further development.

To be able to represent reality as good as possible and to make the system attractive for use, more data should be collected, to develop new indicators that precisely fit the needs of policy makers. These indicators could for example be:

- The assessment of actual demand and capacity evaluation (this would require highly disaggregated vehicle occupancy and boarding/alighting data).
- Better disaggregated trip demand and income distribution (this would require land use maps and estimations of jobs, income and population density on a disaggregated scale).
- The effects of specific link and junction priority measures through the inclusion of road classification (this would require more information about road classification and average speeds in Kigali and is dependent on the scale of the proposed priority measures).
- The inclusion of operation characteristics in the fare price calculation, which would make the system more interoperable and friendly to use for non-experts (this would require more information about the connections between vehicle park and operation characteristics and the cost price of operation).
- The introduction of a feedback mechanism between operation changes and passenger demand (this would require demand elasticity figures and traffic count time series).

It is also important to implement a time dependant assumption and indicator set, that can be able to evaluate the effects of population and land use changes. This was also one of the targets of this project, but not enough data was available to represent this feature correctly.

6.5 Discussion

The use of a PSS for public transport rationalization is a rather new research field, which has a lot of possibilities. This exploring research can therefore be used in further studies on the properties of rationalization of public transport in developing countries and the use of PSS to support this practice. As the characteristics of the Kigali public transport system are similar to other urban transport systems in Sub-Saharan Africa, this would be an area of interest for further use of the outcomes of this study.

The planning support approach proposed in this research is new and has not often been implemented in this way in a real setting, both in the developing and developed world. Such a system could also be useful in developed countries, but their governments often have requirements of detail and quality of the model that are much higher, which would lead them to traditional transport models. The PSS approach is probably most useful in developing countries or countries in transition, as the use of a PSS is most valuable in settings where data and knowledge are not readily available. Further research on this topic should therefore focus on applying PSS in transport planning in developing countries, which have corresponding requirements and high potential for improvement.

While in the last phase of this research I came across an online newspaper article mentioning a recent new public transport strategy for Kigali (Nsanzimana, 2012). This strategy describes the assignment of routes to certain operator companies and cooperatives, with the aim of making the public transport system more efficient. Plans for this strategy were not mentioned to me during the field study, so I assume that this vision was developed rather recently.

It is however questionable if such a strategy is made in a rational way, considering the tools and data available for such policy making. This is also clear from the negative comments that were made by citizens of Kigali on this article. The article mentions the wish of operators and the government to respect passengers and to cooperate with them in upgrading the service, but this is not yet fully functioning.

It is therefore clear that, although the practice of passenger oriented public transport planning is on its way in Kigali, there is a long way to go. The rationalization principles and prototype PSS proposed in this research could hopefully be of help in developing this practice further.

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Appendices

Appendix 1
Personal experiences during field study

Institutional observations

- There are a few different institutions (MININFRA, KCC, RURA, Rwanda Transport Development Board RTDA, individual operators), each responsible for their own part of the public transport planning and regulation process.
- Institutions responsible for planning (parts of) the public transport network do not seem to cooperate much outside of official meetings. Each institution primarily makes its own plans and has its own experts.
- When new decisions have to be made, this happens in multi-stakeholder meetings where all stakeholders defend their own interests or those of their clients. It is not clear whether some stakeholders are more powerful in this decision-making process.
- It seems to be very hard to procure software packages within the governmental organizations, as this has to be validated and approved multiple times, resulting in difficult and long-lasting procedures.

Planning and policy related observations

- Land use and public transport planning do not seem to be tailored to each other, as they are developed in different institutions. The discussions between land use and transport planners are not well-structured, as it is not always clear which assumptions they use.
- Land use and transport planning and construction assignments are usually assigned to (foreign) consultancy companies instead of handling them internally by local experts.
- Public transport planning seems to be heavily guided by the market, especially by the operators. The impression is that management of the amount of vehicles and frequency per route is almost completely left free to the operators. This seems to be done in an attempt to let the market regulate this, but it seems like a one-sided (demand is not taken into account actively) and sub-optimal approach.

Data availability

- Some stakeholders in the planning process are very careful with providing information and data. They often request official data request letters before agreeing to provide this data, even when it is to another department within the same organization. This might have to do with negative experiences with data sharing in history.
- There is a lack of integration of the data owned by all planning stakeholders. Most stakeholders do not have access to all data and the people who do make few efforts to combine data in an integrated way
- Most available data sources are out-dated or incomplete or are not available digitally. There is no central organization reviewing the available data of the public transport system.
- Detailed data about the demand for public transport is not available to most planning institutions. Optimization for demand does not seem to be a key target.

Observations of the public transport system

- There is almost always a bus available at the most used bus stops, but they are either waiting for a long time to fill up (during off-peak hours) or they only have space for one or two people while there is a much larger group waiting (during peak hours)

- In the peak hours, it is almost impossible to get onto a bus at the first few stops after the terminal, because all buses fill up at the terminal with people going to remote locations.
- There is no visual information available to travellers about the network, location of stops, routes visiting a stop and prices for each route. All information must be retrieved verbally by either asking other passengers or the driver or conductor.
- The large buses seem to have problems climbing the hills of Kigali and turning the sharp corners (compared to the smaller buses), resulting in extra emissions by these vehicles
- There is no clear internal record of the state of maintenance and pollution class of each operating vehicle.
- There seems to be little obvious fraud or illegal operation in the public transport system of Kigali City
- It is not clear if public transport operators are making rational decisions by waiting at bus stops until their buses are full. It might be possible that if they would have a continuous operation, their profits would not shrink too much.
- The fare is usually paid per route, although it might be possible to pay a decreased rate after negotiation when boarding half-way along the route.
- Transferring between buses is not easy, as there is no transfer fare policy and important routes do not intersect at key locations
- Next to the driver and conductor of the buses, there sometimes is an extra person who helps promoting the bus at places where many people disembark. This is probably because the driver and conductor want to driver further both quick and with a full bus. The “extra conductor” is paid a small price informally and stays behind at the bus stop.
- Buses usually only stop at bus stops, but they sometimes pick up some extra passengers along the road when no traffic police is around.

Observations of the general transport system

- There is air pollution by engine exhaust on the most used roads through the city, especially during the peak hours. This pollution is worst on dry days and clears after rainy periods.
- A lot of people use the motor-taxi’s, as they are easily available (also during peak hours) and are fast and reliable (they can avoid traffic jams). As the normal fare price is 3 to 4 times higher than that of a minibus, it is clear that reliability and availability are important aspects for these people.
- During peak hours, there are traffic jams at the busiest junctions, roundabouts and traffic lights. As traffic lights only use a static program, their operation is taken over by traffic police directing the traffic at these junctions during the peak hours.
- A lot of drivers of private vehicles and minibuses drive very carefully, possibly because of a disability to correctly estimate traffic conditions. This results in frequent small braking and pulling up movements, which results in more engine exhaust and therefore air pollution.
- There are some large speed bumps in the city to slow down traffic, but seem to have only a very local effect on vehicle speed and result in a relatively large amount of local emissions.

Comparison of transport system with field trip to Kampala (Uganda)

- Kampala is an East-African city comparable to Kigali in some ways. It might be a mirror for how Kigali could grow in social and economic way in future years. Kigali however seems to be much stricter in urban development planning.

- In Kampala, which is a much larger city, there are a lot more buses then in Kigali. Most buses are a bit smaller (only 14 seats), but there is also a clear effort of introducing larger buses.
- The larger buses meet a lot of trouble in the way they are loaded. During peak hours, they are overcrowded with people, possibly even exceeding the allowed amount of standing places. All people have to pay at the driver before entering, resulting in very long routes at the bus stops and inefficient loading
- The minibuses operate in the same way as in Kigali, but they do not stop at clear bus stops, although their stops seem to be the same each time.
- The congestion and pollution by traffic engine exhaust is much worse in Kampala then in Kigali. This is partly due to the larger amount of private vehicles and motorcycles, but also probably due to the larger minibus fleet.
- Compared to Kampala, the public transport system in Kigali seems very orderly. This mainly has to do with the difference in size and the tendency of orderly central government in Rwanda.

Appendix 2
Interview Jean-Claude Rurangwa

Interview Jean-Claude Rurangwa, Kigali City Council Transport Expert (24-04-2012)

This interview was undertaken as an semi-structured interview, with predefined questions but in a dynamic sequence. All questions have been answered, and the answers are provided in order of topic instead of in chronological order. Some questions have not been posed in this way and to most questions extra sub-questions were asked to extract more information.

What is the number of buses of each type in Kigali City?

3 types of buses:

- *Minibuses (17 seats)*
- *Coasters (28 seats)*
- *Large buses (60 seats)*

The size and age distribution of all buses is not known, but can be retrieved via RURA. They keep a complete list of all buses.

These data should come forward from RURA

How are these buses licenced and how are the fare prices composed?

Until some time ago, every bus operator determined their route himself. This is now regulated through licenses. The licensing of buses is done by RURA (Rwandan Utility Regulation Authority). This is a national company with many responsibilities, and they are not only focused on transport. Operators can apply for a license at RURA. These licenses are given for each individual vehicle and are mainly based on the insurance of the operator for the vehicle. The time period for the license is set considering the remaining time period of the insurance. There is no maximum time period for licenses and there is no active discouragement of using the license for many years. (From the interview) it is not clear if these licenses are also dependent on other criteria.

The fare price of all routes is not recorded in the license, but is reviewed from time to time in a multi-stakeholder meeting organized by RURA. The price is based on a set of factors related to operating costs with a profit. It is reviewed mainly after fuel price fluctuations or other changes in operating costs.

This should be further explored in an interview with an expert at RURA

What is the policy of Kigali City Council towards the size of buses and the size of the entire fleet and how is this fleet organized?

Before 2008, there were only minibuses in Kigali City. Since 2008 larger buses have entered, especially the large buses owned by bus company KBS (Kigali Bus Services). Some minibus owners (all minibuses are privately owned, usually by drivers) have moved to the larger and more comfortable coasters, which they have bought themselves.

Since this year, the City of Kigali (through RURA) does not issue licences for minibuses anymore. Any expired or new licences have to be for coasters and large buses.

Practically all large busses are currently in possession of KBS, which is a private company. There has been an uprising lately by some minibus drivers. They are all private entrepreneurs, a lot of whom were previously arranged in an association called ATRACO. They have recently rearranged themselves in a cooperative called R.F.T.C (Rwanda Federation of Transport Cooperatives), which has a business structure. They have made agreements to save some money collectively, to be able to buy or lease larger buses in the long term. They are however not ready yet to introduce a collective fare collection system.

What are the future development plans for the public transport sector in terms of infrastructure development, route planning, operation changes and information provision?

The Kigali City Council is currently investigating the introduction of bus priority measures at junctions and congested roads. This will not be incorporated in traffic light schemes, but will rather include the construction of bypass lanes for buses at signalized junctions and possibly the use of bypass roads along congested routes.

There are plans to look at bus stop spacing, as some of them are currently very far from each other. The criteria that are sometimes used to assess bus stops are the following:

- *Proximity of junctions and road side objects (bus stops will not be placed close to these objects)*
- *Demand analysis, based on street surveys (asking about OD and currently used bus stops), expert knowledge and requests by civilians*
- *The current inter-distance, which should not be too heterogeneous*

There are currently no good options for creating new routes, as there are not enough vehicles available to cover the operation of these routes.

In the future it would be good to introduce an integrated fare collection and revenue-sharing system, because this would reduce the problem of the unreliable scheduling. This has however created some friction from the City Council and MININFRA, as they are not yet sure what effects this would have on productivity and entrepreneurship of operators and relations between drivers. It is certain that a system like that should rely on a watertight ticketing or smartcard fare collection system.

There is currently a tender for the creation of new bus stops. There will be space reserved on these bus stops for information provision towards passengers, but it is not yet sure which information shall be provided. Possible options are the name of the bus stop and the destinations of routes that are visiting it.

What is your judgement on the current operation of public transport?

It is a known problem that the minibuses are waiting at the terminal to fill up. This is causing unreliability of operation for bus stops along the route. This is also the problem with the larger coasters, but large buses tend to make a more continuous round trip. There is officially a regulation for buses to only wait for a certain amount of time at each on-route bus stop, but it is hard to enforce.

There is no regulation for leaving the terminal or remote bus stop and proposing this might lead to discussion with operators, as it may have effects on the profitability of their operation.

What are your targets visions for the public transport system?

The public transport system should mainly be improved to reduce the amount of congestion on the street by private transport. To make people shift from their car to the bus, reducing time delay is very important. This delay can be split in three focus areas:

- *Pre-transport (reducing the amount of travel time walking or driving to the bus stop)*
- *Waiting time at the bus stop*
- *Congestion loss time (in congestion, also in buses)*

The importance of this time delay factor can be seen by the extensive use of motor-taxis. While these are 3 to 4 times as expensive and much more dangerous in use, many people prefer to use motors above buses, especially in peak hours as motors are able to avoid most traffic congestion.

How are investments in the public transport system tendered and what are the annual budgets?

The investments for new bus bays and signposts (and probably also for new bus priority measures) are a joint venture of the Kigali City Council and the Road Maintenance Fund. When new investments will be done, this is proposed by the Kigali City Council Transport Department in cooperation with RTDA and the Traffic Police. The price of investments is defined using a tender for financial research. After this, the City Council approves the budget and two new tenders are issued, one for construction and one for supervision on construction. There are no figures of past infrastructure investments currently available to the Transport Department.

Bus shelters are created in a Public-Private-Partnership (PPP) with an advertising company. This company builds the bus shelters and maintenances them for a limited amount of time, paid by the advertising revenues. After this period, maintenance will be taken over by the Kigali City Council, which will also try to pay for maintenance through advertising on the bus stops.

The taxi parks and main terminals in the city are built, operated and maintenanced by private associations, commissioned by the Kigali City Council. In practice, this is done most of the time by cooperatives of drivers, for example by R.F.T.C. Bus operators have to pay for the use of these terminals, which makes a profit that is used to maintenance the area around the terminal.

How are other planned changes in the public transport system proposed and implemented?

The Kigali City Council Transport Department is responsible for introducing public transport plans. These are proposed to all stakeholders in a meeting. This meeting usually includes representatives of the RTDA, RURA, MININFRA, Kigali Traffic Police and the bus operators. In these meetings, the proposed plans are discussed and if necessary adapted. They are most of the time approved by unanimity or a clear majority of stakeholders.

After approval, the plans are further executed by the Kigali City Council and the plans are communicated to all stakeholders in a letter. New developments are published to the public in newspapers and for example on television and radio.

Appendix 3
Interview Deogratias Muvunyi

Interview Deogratias Muvunyi, RURA Director of Road Transport Unit (26-04-2012)

This interview was undertaken as an semi-structured interview, with predefined questions but in a dynamic sequence. All questions have been answered, and the answers are provided in order of topic instead of in chronological order. Some questions have not been posed in this way and to most questions extra sub-questions were asked to extract more information.

What is the structure of RURA and what is its role in the public transport system? Would it be beneficial to make institutional reforms in favour of public transport?

RURA consists of six departments, responsible for Telecommunication services, Electricity supply, Water supply, Gas supply, Waste collection and Transport of people and goods. The authority is placed under the Ministry of Infrastructure. It used to be a part of the Ministry, but it was split so the Ministry could focus on policy making while RURA took the role of being the "referee" in the system.

The Transport department has 3 units, caring about Road Transport, Air Transport and Waterways transport (the focus of the rest of this interview is on the road transport unit).

The Road Transport Unit has a few main tasks:

- *Licensing of all types of public transport, meaning (all types of) buses, taxi-cabs and motor-taxis*
- *Fare setting, by determining the maximum fares public transport operators can ask.*
- *Conflict management amongst operators and between operators and other authorities*
- *Allocating buses along the network, also ensuring the operation of unprofitable routes*

RURA is not connected directly to any of the other stakeholders in the public transport system, although it technically is part of the Ministry of Infrastructure. It however has its own budget and board, so it can remain neutral in discussions. There is a lot of cooperation with road authority RTDA, public transport planners Kigali City Council and the different districts (in the rural areas) and the traffic police. RURA tries to have good connections with all operators, including subsidized government operator ONATRACOM. Within Kigali City it mainly follows the master plans of the Kigali City Council. This is also evident, because all major decisions are made in stakeholder meetings and expert teams, always involving RURA in the decision making.

In the future, RURA thinks it should maybe stay neutral as a referee for the public transport system. It would also not be easy to join the Road Transport department of RURA with another authority, as it is already a very small department but with a broad view, which also extends beyond Kigali City.

How does the licensing of public transport in Kigali City work?

Any person who wants to start offering public transport services can apply for a license. These are issued when the operator meets a few requirements:

- *They have to face technical inspection at the technical inspection centre, which gives them a certificate of good vehicle health. They have to renew this certificate every 6 months.*
- *They need to have an insurance for the vehicle, which allows them to move other people on the vehicle*
- *They can only service the route corresponding to the license at the fare that is set by RURA*
- *The license is only valid for 1 year, after which it can be renewed at RURA*

In the last years, RURA has been urging individual drivers to arrange themselves in cooperatives or companies. They have had several meetings to inform drivers of this and have provided them with help by giving workshops about arranging yourselves in companies. A lot of drivers have joined one of the cooperatives and this will hopefully be a continuous process in the future.

Cooperatives and companies have to meet extra requirements to get licenses:

- *They have to make a business plan for the routes they are going to service, including the expected revenues and the costs they will have to make.*
- *Licenses for companies and cooperatives are valid for 2 years, after which they can be renewed.*
- *The cooperative has to apply for a separate license for every vehicle*

There is a complete document available listing all the license requirements, but it is unfortunately only available in Kinyarwanda.

How many buses of each type are operating in Kigali City?

This can be found in the hardcopy files of RURA, but the only summarized list available shows only the largest 20 cooperations and companies. Their bus sizes are known, but it is not clear which buses drive on which routes, as most companies have multiple types of buses and also multiple operating routes.

How many licenses are issued for each bus route?

Currently there is no maximum number of licenses for each route. Most routes are underserved, which already results in congestion in the peak hours. The amount of licenses applied for is therefore assumed to be the correct amount for each route. This can be further investigated by demand analysis in the future, but this is no main focus.

How are the fare prices for public transport calculated and enforced?

The fare prices for public transport are determined in a meeting with all stakeholders. They consist of a lot of criteria that are further described in a document. It is clear that it exists of a fixed costs component (vehicle depreciation, maintenance, insurance, taxes), a variable costs component (mainly fuel price) and a profit margin, which is around 15-20%. These costs are determined by consultation of operators. After the cost price and profit are determined, the fare price per person kilometre is determined, which leads to the calculation of the prices per route. These are submitted to a stakeholder meeting consisting of all authorities and operators, after which they are rounded and set. In these stakeholder meetings, there are also always consumer protection associations present, which ply for the rights of travellers.

The price set by RURA is a maximum price, from which operators can divert when picking up passengers at other stops than the terminal. It is however not allowed to compete heavily on price or selling tickets below the cost price to take over the market. This cannot be enforced heavily in practice, but abuse can be reported to RURA

<u>The document with fare price calculation criteria must be retrieved from RURA</u>

What is the function of the conflict management by RURA and how is it done?

To check if all drivers are abiding the license requirements, RURA does regular physical inspections of the operators. As they are not able to do this all the time, they need to rely on social control. RURA has a telephone hotline and a website, where complaints from other operators or customers about operators can be issued. These complaints range from people operating routes without a license to the creation of false competition by price reduction.

Multiple complaints will result in a physical control of this operator, which might lead to fines, withdrawal of the license or confiscation of the vehicle. For the latter, RURA has to cooperate with traffic police in some cases.

RURA also acts as a conflict manager or referee between the operators and the transport planning authorities. It tries to make sure all stakeholders do not get their rights violated by malicious decisions.

What is the vision of RURA for the public transport system in the future?

RURA cooperates with other authorities and also has its own vision that minibuses in Kigali City have to be phased out in the future. It therefore does not issue new licenses for minibuses anymore. New entrants have to apply for licenses for coasters or large buses.

A few years ago, there were no coasters or large buses, until they were introduced by amongst others KBS. RURA is welcoming this development, as it fits perfectly into their plans. They are trying to convince the new cooperatives to also adopt larger buses in the near future, in which will be a gradual phasing out of the minibuses and even the coasters.

After some years, when most minibuses would have been phased out and individual operators do no longer exist, there will be a shift to a system of issuing concessions to one company for every route. This would shift the responsibility of serving the demand on each route to the operator, which would allow for more effective public transport. This development will however have to wait until there are only large operators (after fusion into cooperatives), as it will not be feasible with a lot of individual drivers.