Bachelor Thesis

INNOVATIVE DATA: MOBILITY SOLUTIONS IN DEVELOPING COUNTRIES

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Summary

The last few decades have shown unprecedented rapid rates of urbanization. The main reason for this is due to the migration flows from rural-to-urban areas. Urban areas offer a better quality of life and more job opportunities compared to rural areas. The rate of urbanization is still growing rapidly in developing countries. It is projected that most of the world's population will live in urban areas in developing countries in the decades to come. This results in many challenges for these urban areas to cope with the growth, as they struggle to provide their population with basic services.

There is especially increased pressure on the mobility systems in cities of developing countries. The uncontrolled urban growth these cities are experiencing directly influences the quality of mobility in the city. Certain parts of these cities tend to have poor access to links of transportation and the capacity of the infrastructure cannot cope with the pressure. When local authorities are unable to provide adequate and sufficient modes of transportation, the means of informal transportation significantly increase and dominate the majority of cities in developing countries. The unmanageable flow of traffic that subsequently occurs leads to traffic congestion and therefore longer duration of commutes.

For local authorities to be able to combat the deteriorating quality of mobility, they must intervene and implement solutions that tackle the problems. However, to do so, they require reliable data on the mobility system of the city. Local authorities in developing countries often lack this mobility data. Traditional methods of collecting such mobility data, such as traffic sensors and surveys, are often not viable options as they are financially unattainable or too time consuming. Nevertheless, there is an abundance of data already in circulation through innovative sources, such as mobile phones. If local authorities could harness this data from mobile phones, such as GPS data and phone transactions, it could provide them with the reliable data that they are missing.

The local authorities are often unaware of the possibilities that exist in capturing data from innovative sources and lack the expertise to utilize these sources. Therefore, this research's aim is to explore the opportunities that may exist if they collaborate with private organisations, that could provide them with the knowledge they need to do so. Furthermore, this research aims to find out in which manner such collaborations could take form and what impact this could subsequently has on providing reliable data to implement solutions. The main research question is therefore: *"How can innovative sources of data from collaborations between local governments and private organisations be used in urban planning/ policy decisions to improve mobility in cities in developing countries?"*

To answer the main research question of this research, two main methods were chosen to retrieve the required information. The first method was to map out several cases that fit the profile of developing countries, where there has been a project that attempted to use an innovative source for mobility data. These case studies were then compared and analyzed on their impact and effectiveness; this was conducted in a case studies framework.

The second approach was a semi-structured literature review that provided an in-depth overview different aspects such as types of sources, benefits, opportunities, challenges and more.

The results of the two approaches were combined to create a clear overview to be able to make assumptions from the research. These assumptions lead to the main conclusion of the research. It became apparent that by using innovative sources to gather mobility data provided local authorities with analysis' that were once unattainable, due to the challenges bound with traditional sources for mobility data. When local authorities collaborate with private organisations this leads to an efficient and effective manner to collect reliable data that in turn allows urban planners to make evidence-based interventions and thus improving the quality of mobility.

1. Project Context

Over half of the world's population – more than 4 billion people - are urban dwellers. The last 70 years have revealed a rapid growth of cities and their population; the phenomenon known as urbanisation. The main contributors to this rapid rate of urbanisation are the migration flow from rural-to-urban areas, the natural increase of population and the transformation of rural areas into urban settlements. According to projections of future urban growth till 2050, all population growth is anticipated to occur in urban areas. This means that the rapid rate of urbanisation will continue and even drastically increase. By 2050, over 80% of the world's total population is predicted to live in urban areas in less developed countries, mostly in Africa and Asia (United Nations, 2019).
From here onwards, these less developed regions will be referred to as 'developing countries'.

Cities have the potential to provide their dwellers with an improved quality of life in terms of employment opportunities, safe shelter and access to basic necessities. However, for this to happen, they have to be managed properly (Dhaliwal & Huikuri, 2018). Unfortunately, due to the uncontrollable rapid urbanisation in developing countries, the cities are problematic to manage, consequently they face many challenges. Many urban dwellers in the developing countries live in poverty, these urban poor often reside in informal housing such as slums as a result of inefficient urban planning. These types of informal housing are of poor infrastructural quality and lack basic living necessities such as water and electricity.

In contrast to rural dwellers, living in an urban environment is much more dependent on cash income to provide them with basic goods and services such as food, transportation and education. Additionally, the urban poor live in densely populated areas, making them more prone to health risks (Lucci, 2014).

Most of the world's emerging cities - cities that accommodate a population of over a million - are in developing countries, a few of these cities are Dar es Salaam, Addis Ababa and Malappuram (United Nations, 2019). These cities are exceeding their capacity, local governments are facing serious complications to provide their urban dwellers with basic services. The rate of growth of these cities is a recipe for disaster and further declines the ability to provide basic services. Local governments have to act sooner rather than later, to be able to cope with these challenges and attempt to keep up with the growth projections (Cohen, 2006).

For local governments to be able to intervene and implement policies that improve basic services, it is required that they have reliable data to provide them with information and to identify the problems they are facing. However, local governments in developing countries lack this flow of crucial primary data, that is required to be analysed and evaluated to allow for the implementation of effective policies. This prevents them from bringing change to current situations. The local governments in developing countries often face shortages of finances to improve the cities' infrastructure and provision of basic services. To invest in data generating information systems is therefore not a viable solution in most cases. Nevertheless, there are alternatives to still be able to generate a sufficient level of primary data, by collaborating with private organisations that could provide the local governments with innovative sources of data. This reveals a wide range of opportunities to bring spatial change to cities and to improve the well-being of its dwellers (Navarro, 2001).

2. **Research Objective**

In order for this research to successfully contribute towards a solution for the deteriorating well-being of urban dwellers in developing countries, the aim of this research has to be demarcated from the wider context of the project (Verschuren & Doorewaard, 2010).
One of the main problems in emerging cities in developing countries is access to reliable mobility infrastructures. The uncontrolled growth of cities has negative impacts on the accessibility of these cities. The capacity of the existing infrastructures can't cope with the immense growth of the cities, the increased growth leads to increased usage and pressure on mobility. Several characteristics are that: Traffic is not properly managed such as by traffic lights, the cities are not built to withstand motorised traffic meaning there are insufficient designated roads, public transportation is over-crowded and often unaffordable for the urban poor. As a consequence of these factors, congestion arises and commute times are unnecessarily high (Gakenheimer, 1999).

Furthermore, the mobility conditions in developing countries cause unsafe circumstances, this leads to traffic accidents. Over 90% of the global deaths that occur in traffic are in developing countries (Murali, et al., 2018). Namely, the highest rates of traffic-related deaths are in Africa, with 26.6 deaths every 100,000 people (World Health Organization, 2018).

Advancements in technology can contribute to the improvement of living conditions of urban dwellers in developing countries, specifically with regards to their mobility within the city. Innovative types of data sources could be extracted from for example mobile activity databases in order to analyse and understand traffic situations. These types of data could then contribute towards a solution to improve the management of traffic situations. Such innovative data is often possessed by private organisations, namely mobile service providers and other type of service providers. Local governments are often unaware of the availability of such innovative types of data and don't know how to unlock their potential in implementing policies (GSMA, 2020).

This research aims to contribute to the knowledge about the application of innovative data sources to provide urban planners with reliable data to implement successful interventions. An attempt will be made to explore how collaborations between private organisations and local governments could aid in the generating of reliable mobility data using innovative sources. This will be done by analysing current cases where such innovations have been implemented, aiming to seek out the reasons for the implementations, how they were implemented and finally what their impact is. Ultimately, this allows this research to provide insights about the implementations and how they could improve mobility in cities of developing countries.

2.1. Scientific Relevance

There is a magnitude of literature about the process of urbanisation and how this in turn results in challenges for urban areas in developing countries (Cohen, 2006; McGranahan & Satterthwaite, 2014; Abimbola & Pauline, 2015). There is also an abundance of literature about mobility issues in these cities and how improved mobility can improve the quality of life of urban dwellers (Witkowski & Kiba-Janiak, 2012; Steg & Gifford, 2005). Some of the literature provide solutions for these issues. Detter (2015) proposes to centralise the planning of the urban area and the improvement of public transport infrastructure. While Gakenheimer (1999) states that it is a viable option to implement policies that restrict usage

of vehicles and roads, with the combination of providing higher quality public transportation. Many of these solutions require high financial investments that may be unattainable for cities in developing countries.

Innovative sources of data are a relatively new topic, the literature has revealed that it may be beneficial for urban planners. However, there are gaps in the literature in how these innovative sources could be more beneficial than traditional sources. Also, there is a gap in the literature with regards to how such data can be can generated through collaborations and what the impact of such collaborations are on the quality of mobility. This research aims to address these gaps and will therefore contribute to the existing knowledge and will in this way serve its scientific relevance.

2.2. Societal Relevance

By providing insights that could be used by local governments about how to make the cities more accessible to its dwellers, solutions could be implemented and policies that are ineffective could be eliminated. This research ultimately intends to contribute to the living conditions and quality of life of vulnerable communities in developing countries. Furthermore, it could bring emerging cities in developing countries a step closer to reaching the 11th sustainable development goal 'sustainable cities and communities', by means of contributing to sustainable transportation (United Nations Development Programme, 2021). In this manner, this research also functions its societal relevance.

3. Research Framework

3.1. Research Questions

In order for this research to successfully accomplish in retrieving the results that are intended, the following central research question has been formulated:

How can innovative sources of data from collaborations between local governments and private organisations be used in urban planning/ policy decisions to improve mobility in cities in developing countries?

To adequately be able to answer this research question, a set of sub-questions are derived from the central research question:

1. *What type of data is there to solve mobility problems, and what type of innovative data?*
2. *How can local governments and private organisations collaborate to generate innovative sources of data?*
3. *How can local governments of cities in developing countries implement mobility solutions using innovative sources of data, and how effective are these solutions in improving urban mobility?*

3.2. Theoretical Framework

3.2.1. Mobility issues in cities of developing countries

Several literature sources indicate a relationship between urban sprawl and the influences it has on mobility and transportation within a city (Travisi, Camagni, & Nijkamp, 2010; Zhao, 2010; Rode, 2013). Urban sprawl is known to have a negative influence such as a deterioration of the quality of life and increasing costs bound to transportation. This is a result of sprawl leading to unmanaged patterns in which living areas develop and the different manners of travel that are accessible to these areas (Travisi, Camagni, & Nijkamp, 2010).

Local governments in developing countries struggle with managing the urban expansion resulting in transportation issues in cities. Policy makers lack the resources due to poverty to be able to manage the urban areas adequately (Kombe, 2005). According to a research by Angel et al. (2011) the urbanized area of developing countries is expected to grow 3 times in size by 2030. Since developing countries face the challenge of having an insufficient number of roads for public transportation. The rapid growth caused by urbanization increases travel distances and makes urban dwellers more dependent on the usage of motorized type of transportation, which in turn generates increased travel duration (Zhao, 2010). Rode (2013) mentions that the shift towards more motorized forms of transportation is specifically relevant for developing countries and that this contributes to the increasing travel congestion in cities, which indirectly leads to loss of economic productivity. Also, the author mentions that the further growth of the population places immense pressures on future development of urban transportation structures. It is projected that by 2050, developing countries will host approximately 2400 million motorized vehicles, that is almost half (48%) of the world's total of motorized vehicles (United Nations Centre for Human Settlements

(Habitat), 2001). This is a challenge that urban planners have to account for in their mobility policies now.

Urban planners in developing countries often focus on non-evidence-based approaches such as expanding road networks, width of roads and the supplying of more parking spaces, these are unrealistic because the existing urban structure often does not allow for these requirements to be met. Furthermore, policies regarding urban planning for transportation often lack the consideration of the urban poor, whom main modes of transportation are usually non-motorized, such as walking and cycling (United Nations Human Settlements Programme (UN-Habitat), 2003). These non-motorized means of transportation are usually linked with poverty and urban planners usually try to eliminate them rather than improve the links of transportation for these non-motorized modes. Other complications for the urban poor are that most job opportunities reside in the center of the city and many of the urban poor live in the outskirts of cities, this makes travelling to work time and money consuming. The urban poor often don't have access to a means of privatized transportation, especially the elderly and women, which results in them having to travel by means of overcrowded and expensive public transportation. For those not able to afford public transportation means they are excluded from labour, leading to a loss of income and not being able to afford basic services (United Nations Centre for Human Settlements (Habitat), 2001).

Improving mobility should entail the reduction of travel costs, delays, risks and travel speeds throughout a city. While making it more accessible, is to make it inclusive for all urban dwellers and provide sufficient opportunities for urban dwellers to be able to commute within the city (Litman, 2003). Solutions have been implemented worldwide to make cities more accessible and improve transportation links. Finding ways to transport large number of people and shortening travel times are some of the main challenges to be tackled by urban planners. Various manners in which the pressure on vehicle infrastructure could be alleviated, is through the construction of other means of transportation such as railway, tramway and underground connections, for public transit by trains/ trams/ metros. Public transportation has the potential to directly address congestion problems. However, for less developed countries this is often financially unattainable, and the implementation of public transportation is time consuming. Busses are viable options due to that the infrastructure does not have to be adapted as they could make use of existing roads, but they also have to cope with congestion. It would be preferable if busses could have their own driving lane, which unfortunately is not always possible (Detter, 2015). United Nations Centre for Human Settlements (Habitat) (2001) agrees that alternative modes of public transportation systems should be implemented. Bus infrastructure should receive priority as it has the potential to relieve congestion; noting that busses that are stuck in congestion do not solve the problem.

Perhaps the most straightforward solution is the improvement of the road infrastructure. Olsson (2009, p. 477) states that *"road improvement will lead to direct effects in the form of reduced journey time, reduced costs and improved reliability."* These improvements influence not only urban dwellers but also businesses, resulting in positive economic advancements and creating more job opportunities. This point of economic development is also reflected in a report by Lakshmanan & Chatterjee (2005) who state that improving transport networks has been beneficial to the economy since the mercantile era.

Other means of improving mobility in cities is the stimulating of alternative modes of transportation. The separation of different modes of transportation such as designating specific roads for pedestrians and cyclists. This requires the altering of the already existing infrastructure and does not require huge investments (Sietchiping, Permezel, & Ngomsi, 2012). Low-cost methods to achieve such implementations are for example, raising the pedestrian walk space and colour coding areas designated for different modes of transportation (Roberts & Babinard, 2004).

The mentioned impacts that urban sprawl have on mobility in a city, and the relationship this has with the interventions of urban planners, are visualised in figure 1.

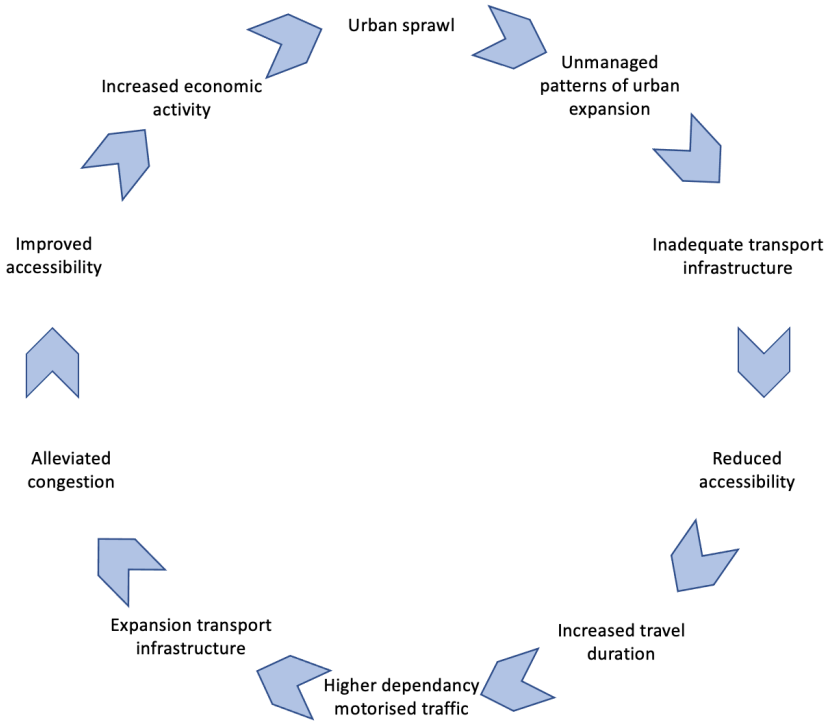

Figure 1: Relationship urban sprawl and mobility

3.2.2. Innovative data opportunities for developing countries

For urban planners to be able to analyse existing structures and make decisions on how changes could be implemented in their policies, it is necessary that they don't lack data that could measure the performance of the existing transport systems (Meyer, 2000). Unfortunately, in many of the developing countries around the world a scarcity of data exists, this is because these countries don't have either the capacity or the resources to collect such data. Therefore, there is a shortage of data to be analysed and to be used by urban planners to create policies using relevant and up-to-date data. However, big data, collected through mobile networks, such as mobile transactions and GPS data, offer opportunities to create data sets for specific activities within a city. It can in turn be used to implement policies that tackle social, environmental and economic problems (International Development Research Centre, 2016). Williams (2018) states that it is indeed too difficult and costly for many developing countries to collect data, and that if they do collect data that it is usually of poor quality, making it unreliable for effective policymaking. Big data is more reliable and is already being collected for many activities in developing countries. Private

organisations collect this data in developing countries (and almost every other place in the world) to sell to big multinational corporations such as Google and social media corporations. If this type of big data were to become accessible to local governments, it could immensely help with the development and implementation of policies that could help urban dwellers. Though for this to happen, the data needs to be processed in a way that makes sure that the privacy of whom the data is collected is protected. The identity of whom the data is collected from is not a necessary requirement for the data to be practical. There are several tools and methods for the data to be extracted, data such as location, without it comprising the identity of a person. Making the data beneficial to analyse for example travel behaviour of certain groups without associating it to a person (GSMA, 2017).

The generation of big data happens through the digital networks that are already present in many cities around the world, such as phones, satellites, security cameras, weather measurement equipment and much more (The World Bank Group, 2017). Through these types of data producing equipment, it is possible to provide solutions such as geographical tracking (GIS tracking) to map out sanitation facilities or manage peak traffic moments. The 'Internet of Things' is a system created to collect, interpret and send data through mobile and internet networks. It allows for interventions in the places that require it the most. A start-up in Kenya uses this system to manage water and make it accessible to urban poor communities. Another example is big data being used to manage waste, by allowing waste to be collected off-grid, waste that would otherwise not be collected. Big data also provides solutions for urban transportation, it can make transportation more accessible for the urban poor that live in peripheral areas of cities. Big data allows for an analysis of the locations of urban poor, allowing for conveniently located bus stops for those communities. But it also allows to track traffic patterns so that peak traffic could be mitigated to reduce congestion (GSMA, 2020).
IBM set up a programme to research traffic flows in Kenya using big data, the organization set up a network of inexpensive cameras and it analyses the images taken with algorithms to make predictions about the flow of traffic. The outcome is that this data can be used to combat congestion in a low-cost manner but with a huge impact (The World Bank Group, 2017). Another case is in the Philippines, where GPS data was collected from over half a million taxi drivers to gain insights on congestion patterns and duration of trips. This data was shared with local governments, which provided them with crucial information that had not been available to them before (Williams, 2018).

According to Milne & Watling (2019, p.235) a wide range of big data could be used to improve urban transport, these include *"Data from government transactions (e.g. tax, social security), Data related to official registration/licensing, Commercial transactions by individuals and organisations, Internet data from search and social networking activities, Tracking data, Image data (e.g. aerial/satellite images, land-based video)"* because they provide information about activities concerning commuting and provide an indication of where and how many people are headed to. The authors also mention that big data should replace traditional methods of collecting data (surveys) because big data provides more information in less time. Willumsen (2021) agrees that traditional manners of collecting data are less efficient as these methods require higher costs and cover less of the population. By means of data collected through mobile phones (GPS, Bluetooth and WiFi), it is possible to attain information about complete trips instead of just portions of trips. However, the article states that even though big data provides more valuable information, it should not

completely replace traditional methods of data collection, but the two types of data should be complementary to each other. This should allow for better modelling of urban transport systems and improved policies.

3.3. Conceptual Framework

Several sources of literature, from a variety of authors, have been studied and reviewed. This allows for various key concepts to be formulated in order to guide this research further in the right direction. The formulated key concepts are briefly summarised.

Innovative sources of data: Large amounts of data that are generated through digital sources, mostly by users of mobile and GPS networks, but also via electronic equipment throughout cities.

Private organisations: Local and International private organisations and/or businesses that collect data generated by innovative sources.

Local governments in developing countries: Local governments of developing countries that are experiencing immense urban growth and face challenges to cope with the consequences of this urban growth.

Urban mobility: The level of accessibility of a city for its urban dwellers, such as (public) transportation links, travel distance and duration, road safety and inclusiveness.
This research will primarily focus on the links between these key concepts. Ultimately, this research will provide insights on how collaborations between 'local governments in developing countries' and 'private organisations' could contribute to the generating and sharing of 'innovative sources of data' in order to create databases that could be used to improve 'urban mobility'. This is done to answer the main research question '*How can innovative sources of data from collaborations between local governments and private organisations be used in urban planning/ policy decisions to improve mobility in cities in developing countries?*'

A hypothesis has been formulated to be tested during this research:
'*Increasing collaborations between local governments and private organisation, will result in reliable data that can be used to implement solutions that improve the quality of mobility in cities of developing countries*'

This hypothesis is illustrated in a conceptual model:

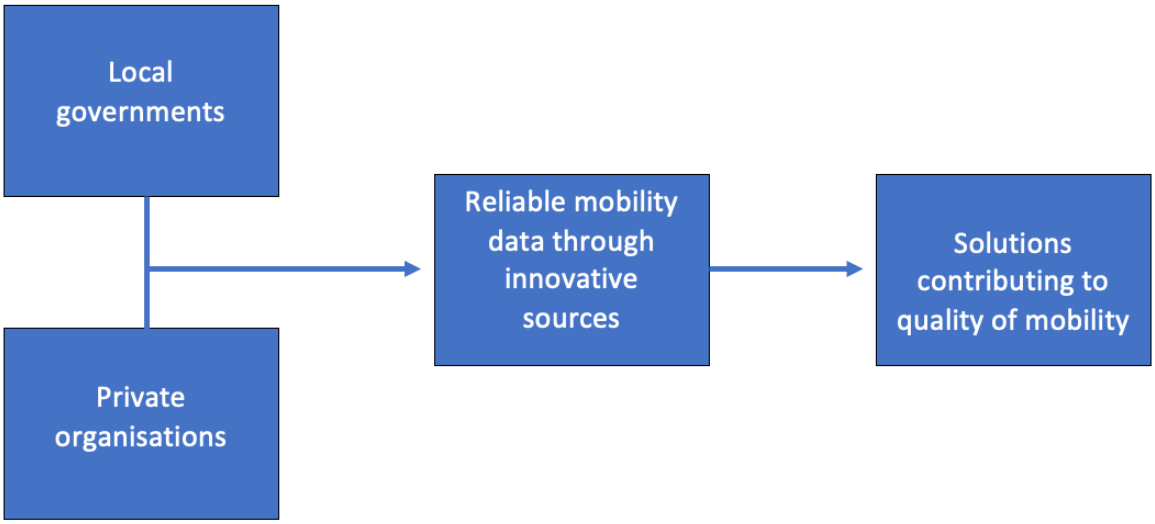

Figure 2: Conceptual model of research

In this conceptual model, when there are collaborations between local governments and private organisations, there is a direct effect on the availability of reliable mobility data through innovative sources. Subsequently, this has a direct effect on the availability of solutions that contribute to improving the quality of mobility.

4. **Research strategy**

4.1. Type of research

The nature of this study will be an in-depth approach to gain insights on the methods, reasons, and effectiveness of innovative data solutions to tackle mobility issues in cities of developing countries, as opposed to using traditional methods to collect mobility data. It will therefore take the form of a qualitative research to be able to describe the implementations and their impact adequately, by focusing on specific implementations, areas and stakeholders. The qualitative form of research provides an opportunity to provide depth about a topic and provide a descriptive overview of a situation. This can be achieved by consulting various different types of data and pinpointing the different factors that have an impact on a situation (Creswell & Poth, 2018). This makes it applicable for this research because the topic of innovative data is a developing topic with gaps in the knowledge. The mode of researching will mostly involve non-empirical methods.

4.2. Research methods & materials

The methods used in this research will take on several forms. The first approach will be to review and analyse numerous case studies to map cases and identify key stakeholders in each case, this will be accomplished in two steps. The first step is to study cases where collaborations between local governments and private organisations sharing innovative data has occurred (or still is occurring). These cases have to be relevant to this research, so they must be about urban mobility data and situated in less developing countries.
The second step is to identify involved parties, such as organisations or investors, that participate in the supporting, enabling and executing of innovative data partnerships with regards to urban planning, specifically urban mobility. Examples of case studies would be the aforementioned congestion relief plans in Kenya (The World Bank Group, 2017) and the taxi GPS tracking plan in the Philippines (Williams, 2018). While enabling parties could be global digital solution providers such as GSMA (GSMA, 2019).

For each case that will be studied, a review will be included to describe the situation and features of each case separately. This will provide a detailed account of each case and will contribute to answering the research questions. In order to identify patterns and make assumptions from the cases that will be studied, a case study framework will be composed in Microsoft Excel. The framework will highlight different categories that are present in each case study. These categories will be the problem tackled in the case, the mode of transportation approached, the approach to collecting innovative sources of data, which types of data are collected, how the data is applied, how effective the data and outcome are, and the involved stakeholders. This will serve as the primary data of this research and will be used to compile a comparison and analysis of the cases.

The case studies to be studied in this research must be relevant to the context of this research to accurately answer the research questions formulated. A set of justification requirements is set for the selection of case studies:

- The cases must be of cities in developing countries that are experiencing rapid rates of urbanisation.
- The cases must have attempted to increase reliable data on mobility flows and systems within the city.
- The cases must have implemented a manner to collect, analyse and use innovative sources of data, as opposed to traditional sources of data, to gain mobility data.

The second approach is to construct a semi-structured literature review. The literature review will include relevant grey literature with regards to innovative data sharing collaborations of private organisations with governments, to contribute to the development of developing countries. These sources of grey literature will be specifically about the topic of urban mobility. For this step, a particular emphasises will be placed on opportunities and barriers to be identified in the literature. Opportunities such as emerging sources of usable data or an increased political will to use innovative data sources. While barriers could be the investments that may be required to process data, such as for data privacy extraction, or to upgrade the public sector (digital) capacity. Examples of sources of grey literature include organisations such as MIT, the World Bank, governmental documents, the World resources institute and several others. These are international organizations that stimulate and aid in financing innovative projects for social good. These sources of grey literature could be (white) papers or internal reports. They are intended for researchers as a report where they provide an in-depth perspective on a relevant issue and share the opinions of their organization, of where they stand on the matter with argumentation. Usually, they also provide examples, or projects they are involved with. To find relevant data, different types of materials will be used. Mainly, the sources will be obtained through the search engines Google Scholar and Google. The sources will include books, government documents, official publications and relevant news articles. The literature review will be semi-structured under headers that each support a specific theme.
The aim of these research methods is to gain a complete image about the impacts of mobility interventions using innovative sources. To find out what the positive and negative effects are of the interventions and if they reach their intended goals or not.

To increase the reliability of the research, sources and cases will be chosen that have a clear outcome to the interventions. Different sources will be used for each case in order to triangulate and confirm findings. While studying the sources, a neutral position will be taken as to be able to assess the intentions of the authors and to not be biased.

To increase the validity of the research. Sources will be filtered to make sure they are reliable and provide an informative intention, instead of a financial gain. Sources will be selected for relevance, so sources should be as recent as possible since information tends to change over time. Since the research is mainly desk research, an attempt will be made to find information as close to this research as possible. If the intention of a source is to answer distinctly different questions, this may have consequences for the results of this research.

5. Desk Research

5.1. Case Study Mapping

5.1.1. Case study: Lima, Peru

The first case to be presented in this research is of the urban mobility situation of the capital of Peru, namely Lima. Lima is situated on the coast of the South American country. With an area size larger than 2,600 km^2 (Wikipedia, n.d.) and hosting over 7.5 million inhabitants (Worldometer, 2021) making Lima the largest city in Peru. Statistics from the UN (United Nations, 2016) showed that in 2016, over 40 percent of Peru's urban population lived in Lima. Also, that by 2030, Lima is projected to have a population of over 12 million inhabitants. Compared to other countries in the world, Peru is classified as a developing country (United Nations, 2020). Lima has the potential to collect data using mobile phones due to the relatively high amount of mobile phone users. In 2018 there were around 131.8 mobile phone subscriptions per 100 people in Peru (The World Bank Group, 2021).

Due to the shortage of means of public transportation in Peru in the past. The Peruvian government allowed that anybody could provide a public transportation service. They allowed this to happen by limiting the restrictions to enter the market, such as eliminating taxes and offering lower prices. This had as a consequence that there would be a surge of informal transportation in Lima, in the form of privately owned minibuses. The poorer population of Lima relies heavily on this form of informal public transportation as they live in the peripheries of the city and need to be able to reach the center of the city where most job opportunities reside (Inter-American Development Bank, 2015). Minibuses as transportation in Lima are popular among poorer inhabitants because it is cheap but mostly because it provides a form of door-to-door transportation, meaning it is more accessible for the population compared to other forms of public transportation (The World Bank Group, 2012).

The transportation sector in Lima is not only limited to minibuses, but there are also alternative means of transportation in the shape of electric trains, metro lines, busses, (motor) taxis and private vehicles (Quinlan, 2018). This combination of traffic with the rapid rate of urbanization of Lima has made the city the 15th most traffic congested city in the world in 2020 (TomTom International B.V., 2021b). This is a result of factors such as an overloaded capacity of roads, public transportation making use of informal stops and the blockage of road intersections due to traffic (Arce, 2020).

This situation of overcrowded roads reduces the urban mobility of all commuters in the city, but it influences people in poverty the most, as the average duration of their trips are 90 to 180 minutes (Inter-American Development Bank, 2015). This is mainly due to the weaker connections and accessibility of (affordable) public transportation from and to the peripheral areas of the city, where most poorer people live. Around 80% of the users of public transportation are some of the poorest inhabitants of the city (The World Bank Group, 2015).

The rapid urbanization and surge of transportation has had further impacts on the state of the urban mobility in Lima. Namely, due to the increase of (unregulated) traffic, the amount of road traffic incidents in 2008 was relatively high at 311 incidents per 100,000 people in Lima, which resulted in 4.8 deaths per 100,000 people. (Miranda, et al., 2014).

Due to the aforementioned issues that have arisen, the local government has taken measures to improve the mobility circumstances. The Ministry of Transport and Communications of Peru, together with the quango organization Autonomous Authority of the Lima Electric Train (AATE) have collaborated with the data processing department of (mobile) phone services provider Telefónica, named LUCA (LUCA, 2021). The collaboration entailed that LUCA would collect data from mobile phones of inhabitants of Lima. The data that was collected was travel times, travel directions and travel purpose. The data was further complemented by data about the people of whom it is collected such as age, sex and other social factors. By collecting and analyzing such data, they were able to predict travel patterns and create a database that could be accessed by AATE. Furthermore, LUCA trained AATE on how to read and analyze information using the database. By such data becoming available for AATE they have been able to use it to optimize their metro line in order to meet the needs of the inhabitants of Lima. As a result, the AATE has been able to plan where to build their metro stations to increase accessibility and increase connectivity between certain points of the city, reduce travel times by making sure there are less transfers and by changing the timetables to better suit the demand at certain times (Telefónica Tech, 2018).

By improving the metro line in Lima, it will relieve the pressure on other types of public transportation in Lima, thus will reduce the amount of congestion on the roads. Also, more jobs will be within one hour of travel time (The World Bank Group, 2015).

5.1.2. Case Study: Nairobi, Kenya

This case will focus on the urban mobility of Nairobi. The African city lies in the southern part of Kenya, where it functions as the capital of the country. The city serves as the main industrial hub of Kenya, it is also the heart of the government. These factors combined have contributed to people migrating from the rural parts of Kenya to Nairobi over the past decades, making it the largest city in Kenya today (Britannica, 2019). The city covers an area of an estimated 696 km^2 (Wikipedia, n.d.). In 2016, the city was home to over 4 million people, containing 32.6 percent of Kenya's urban population. The city's population is expected to grow by 4 percent annually, it is predicted to reach over 7 million people by 2030 (United Nations, 2016).

Nairobi has the potential to collect data using mobile phones due to the relatively high amount of mobile phone users. In 2019 there were around 103.7 mobile phone subscriptions per 100 people in Kenya (The World Bank Group, 2021).

Over 2 million trips take place in Nairobi every day, more than half of these trips are by motorized vehicles (Digital Transport for Africa, 2021). The main method of transportation for inhabitants of Nairobi is by use of the semi-informal network of matatus buses. These type of semi-informal transportation buses are privately owned. They have gained popularity in Nairobi due to the lack of other forms of transportation being provided and invested in by local governments. In Nairobi, there are over 20,000 of these matatus busses that are used by around 70 percent of the inhabitants (Klopp, Orwa, Wagacha, Williams, & White, 2017). The matatu buses cover about 130 bus routes across almost every part of the city and it's outskirts. The buses are owned by multiple different private owners, existing of individuals and companies. These private owners require licenses procured by the local government in Nairobi, however some work illegally. The size of the buses typically ranges from a capacity of 9 to 32 passengers. These semi-informal buses increase the pressure on the city's road infrastructure and further contribute to the congestion in and

around the city. Data about the usage, frequencies and stops of the matatu busses is lacking, this results in several issues. The deficiency of bus schedules constrains the ability to manage the traffic in the city adequately. Also, there is no overview of bus routes, showing where each stop is, some of which are undesignated stops. This does not only contribute to further traffic congestion but is additionally inconvenient for passengers, as they are not able to plan trips. Nairobi's local government's data only included where the routes start and finish, also it did not involve a complete overview of all the city's matatu routes (Williams, Klopp, Orwa, Waiganjo, & White, 2018)

In reaction to these issues that have arisen around the semi-informal matatu bus system, a project was initiated in 2012. The project was initially set up by a collaboration between the 'University of Nairobi', 'Columbia University', 'MIT' and a project design organization that specializes in informal systems named 'Groupshot'. Together they planned the collection of data about all existing matatus bus routes by using smartphone applications. With aid of these applications, they could register and collect data. The data to be collected was GPS information for the location of bus stops, but also bus stop names, occupancy of the buses, bus fares, travel duration and bus schedules. This data was then converted to 'General transit feed specification' (GTFS), such data could be uploaded and processed by Google Maps. After a year of collecting data by travelling the matatu buses, the results were presented to the local government. The Kenya Institute for Public Policy Analysis (KIPPRA) joined the collective effort to analyze the bus system. The end result was the visualization of Nairobi's matatu routes in the form of an official bus route map and real-time information became available on the platform of Google Maps. The project further inspired the creation of a smartphone application, named 'Ma3Route'. This open-source application allows users of the matatu buses to upload real-time information about their trips to further improve travel information such as delays, traffic information and accidents (Williams, White, Waiganjo, Orwa, & Klopp, 2015).

These sources of public data could benefit the local government of Nairobi with the planning of future transportation projects. Such as is the case with the designing of the Bus Rapid Transit system for Nairobi in collaboration with the UN. The matatu bus route map is used as an aid in the project (Digital Matatus, 2015).
Furthermore, another project that was sparked from this data was one to improve road safety. The local government collaborated with the World Bank in a project named 'smarTTrans', that collects data from the 'Ma3Route' application about traffic accidents to create a crash map of Nairobi. Showing where the most dangerous traffic situations occur in order to redesign the roads in Nairobi to become safer (Arguelles, Milusheva, Legovini, & Williams, 2019).

5.1.3. Case Study: Kampala, Uganda

The African city Kampala in Uganda is another case where there have been innovative data collaborations that aim to improve the level of urban mobility within the city. Kampala is the capital city of Uganda and is located in the south of the country. The city is known for its agricultural surroundings along with various other commercial, political and industrial sectors. Uganda's main roads infrastructure originate from Kampala (Britannica, 2021). Uganda's largest city is estimated to be 189km^2 (Wikipedia, n.d.). Kampala is also the largest city in Uganda in terms of population, with over 2 million inhabitants in 2016. The

population is expected to almost double by 2030, with a prediction of more than 3.9 million inhabitants (United Nations, 2016).

In Kampala, the existing transport infrastructure lacks the capacity to meet the demands of the city's dwellers. This is mainly due to the increasing rate of urbanization and the growth of the population. Another reason is due to the reason that the majority of the population relies on modes of public transportation to commute, over 90% of Kampala's population does not have access to a form of private transportation such as a car. Lastly, the public transportation sector is dominated by informal forms of transport such as minibuses that are privately owned, the minibuses typically have a capacity of 14 passengers. This is because the local government has not invested in a structured form of public transportation for its inhabitants. These informal forms of public transportation could set their own fares. As a result, the poorer communities can't always afford to commute via public transportation. Consequently, they end up having to walk for most of their commute and are therefore less productive and miss out on opportunities, leaving them in a cycle of poverty (Ndibatya, Coetzee, & Booysen, 2016).

The road infrastructure in Kampala is inadequate to serve the transportation demand of the city. A typical feature is that roads are overcrowded, sometimes due to them being too narrow. Additionally, the traffic is not managed properly, there aren't enough traffic control workers or traffic lights at large intersections. When events such as car accidents or vehicle failures, there is insufficient space to cope with them, leading to further congestion of traffic. Almost all travel in Kampala, motorized and non-motorized, takes place on roads, this is around 90% of all travel occasions in the city. The traffic congestion that occurs means that road transport travels at speeds of less than 26 kilometers per hour on average (Kampala Capital City Authority). This results in many inhabitants spending hours stuck in traffic each year, reducing overall productivity of city dwellers. It was estimated that travelling from the center of the city to the outskirts of the city, a distance of roughly 5 kilometers could take approximately 30 minutes (Janusz, Kesteloot, Vermeiren, & Van Rompaey, 2019).

As a response to the traffic congestion throughout Kampala, the local government decided to take action in the form of a collaboration project. Due to the high cost and time consumption of surveys to collect traffic data, a different approach was taken. The Kampala Capital City Authority (KCCA), a branch of the local government, collaborated with Dalberg Data Insights (DDI), an organization with the goal to aid in the creation of sustainable cities. The aim of the collaboration project was to collect and analyze traffic data. A tool was developed that would collect data from mobile phone transactions that included information such as travel origin, mode of travel and travel destinations, including the reasons for commuting. Other stakeholders that were included in the development and funding process are ROM Transportation Engineering, a consultancy organization, the United Nations Capital Development Fund and the Belgian Development Cooperation. With the data collected from mobile phones, patterns were constructed that could provide a clear overview of the complete mobility structure in Kampala. Real-time Information such as travel routes, travel times and travel scatter could be visualized to determine bottlenecks in the road infrastructure and identify the busiest routes at certain times. This allows the local

government to effectively compose policies to combat the congestion and aid policymakers in the urban restructuring (Dalberg Data Insights, 2018).

5.1.4. Case Study: Metro Manila, Philippines

Metro Manila, usually referred to as Manila, is a metropolitan region in South-Eastern Asia that has experienced the use of innovative sources to aid in the improvement of the city's urban mobility. It is located on the eastern coast of the Manila Bay in the Philippines. Metro Manila hosts the capital city of the Philippines and serves as the economic and political core of the country. It is also known for its industrial sector and international harbor, both factors requiring a fluent transport infrastructure. The urban agglomeration covers an area of approximately 633 km^2 (Britannica, 2021). Metro Manila had an estimated population of more than 13.1 million inhabitants in 2016 and is projected to grow further to over 16.7million inhabitants by 2030. The agglomeration accounts for 28.6 percent of the Philippines urban population (United Nations, 2016). Metro Manila has the potential to collect data using mobile phones due to the relatively high amount of mobile phone users. In 2019 there were around 154.8 mobile phone subscriptions per 100 people in the Philippines (The World Bank Group, 2021).

Metro Manila is one of the most densely populated areas worldwide, having over 18,500 inhabitants per square kilometer in 2011. The area suffers from congestion on roads due to this high population density, in combination with roads that are too small to encompass the demand. There were almost 2 million motorized vehicles registered in 2008 (Boquet, 2013). In 2021, Manila city was ranked the fourth most congested city in the world, where during rush hour around 188 hours are lost per year (TomTom International B.V., 2021a). The costs this has on the economy is a loss of around 60 million USD per day. The most congestion occurs during the evening rush hour, where travelling a distance of 8 kilometers could take longer than 2 hours (The World Bank Group, 2016).

In an attempt to reduce the traffic congestion in Manila, the local government reached out to The World Bank to collaborate in the collection of innovative sources of data, sources that could be provided at lower costs than that of traditional data collection methods. A branch of the Philippine government, the Metro Manila Development Authority (MMDA), started a project with the World Bank and Grab, a taxi provider service prominent in the area (Tacadena, 2016).

The project is based on a pilot study that was held in Cebu City, also in the Philippines. The project is named 'Open Traffic', which is a software that is developed to receive real-time traffic data. Open Traffic is an open-source project, meaning it could be accessed by the public for input. Data was collected from smartphones of Grab taxi drivers, this allowed for the analysis of the GPS data that was received from the taxis to be able to visualize traffic patterns in the city. It was eventually able to provide reliable real-time information such as durations of trips and when the most congestion occurred in which places. This type of information is available for free and directly, as opposed to traditional methods of data collection (The World Bank Group, 2017).

Traditional methods of data collection, such as traffic monitoring sensors, require a high investment cost and technical specialists to install and maintain the equipment. They are also limited to the locations there installed. Whereas, by collecting GPS data from taxi

drivers, data is collected from everywhere in the city where taxis drive at a rate of around 5 times per minute. Another benefit of the Open Traffic software is that it provides local governments with a platform where the data is visualized, increasing accessibility to analyze the data. The GPS data that is retrieved from taxis is 'raw' data, meaning it has to be processed before it could be used. For this, another open-data software is used called 'Open Street Map', this identifies the type of road that the taxi is driving on. Furthermore, data such as time is also collected, such data is used to calculate the duration of travelling from one point to another (The World Bank Group, 2015).

The availability of the resulting data and analysis provides local governments with evidence to base their implementations on. It could aid with the managing of traffic by analyzing real-time traffic flows and determine where intervention is needed the most. It also has the benefit of being able to evaluate and assess the success of future interventions (The World Bank Group, 2016).

5.1.5. Case Study: Abidjan, Côte d'Ivoire

Abidjan, a city in Western Africa, is another city that is attempting to cope with the increasing pressure on its transport infrastructure. It was once the national capital of Côte d'Ivoire, also known as 'Ivory Coast', nowadays it serves the role of de facto capital of the country. The city of Abidjan is located on the southern coast of Côte d'Ivoire. Abidjan is the economic centre of the country, it includes an international harbour that mostly exports the country's agricultural products (Britannica, 2015). Abidjan spans over an area of 2,119 km^2, making it Côte d'Ivoire's largest city. It is also the countries most populated city (Wikipedia, n.d.). In 2016, Abidjan had a population larger than 5 million inhabitants, expected to grow by 3.1% annually, meaning it is predicted that the population will grow to over 7.7 million inhabitants by 2030. Almost all of Côte d'Ivoire's urban population, around 42 percent, resides in Abidjan (United Nations, 2016). Abidjan has the potential to collect data using mobile phones due to the relatively high amount of mobile phone users. In 2019 there were around 145.3 mobile phone subscriptions per 100 people in Côte d'Ivoire (The World Bank Group, 2021).

Abidjan is urbanizing at a high rate, this is because of the benefits the city provides to its inhabitants. Abidjan has the strongest economy in the country, people that work in Abidjan tend to earn double of what is earned in other cities of Côte d'Ivoire. The availability of services in the city, such as education and other social buildings, contributes further to the popularity of living there. The growing population means there is a growing need for transportation within the city, consequently there is increasing pressure on roads. Over the past decade there has been a rise in people moving from rural areas to the city, which in turn means that there is more poverty. Poorer inhabitants rely either on informal forms of public transportation, such as minibuses, or walking for most of their commutes. Traveling via public transportation accounts for almost 80 percent of all commutes in Abidjan. Typically, poorer inhabitants spend around 3 hours commuting every day, and a quarter of their salary (Morisset, 2019). There are several different modes of public transportation in Abidjan. A relatively small amount of public transportation is provided by the local government, consisting of around 600 buses and 40 ferries. The informal public transportation exists mainly of minibuses and (shared) taxis, accounting for over 28,000 vehicles on the road (The World Bank Group, 2018).

The uncontrolled and unregulated modes of transportation, with the lack of an adequate infrastructure are factors leading to congestion in Abidjan. There is not a sufficient amount of traffic management systems, such as traffic lights, and the quality of roads is insufficient to cope with the demand. This also leads to traffic accidents and an economic loss to the city. It is of importance to improve the level of mobility within the city to increase liveability of its inhabitants (African Development Bank Group, 2019).

The use of an innovative source of data, to mitigate the levels of traffic congestion in Abidjan, was sparked by the telephone service provider 'Orange'. Orange initiated a challenge that entailed the usage of data that they provided publicly, making it 'open-data'. They named the challenge 'Data for Development', the intention of the challenge was to use the data to aid local authorities in Abidjan with the improvement of liveability in the city. The data that was made available existed of Call Detail Records (CDR) of around half a million users of Orange's telephone network, whom identity was cleared from the data. The collected data amassed to over 5 million calls and messages from inside Abidjan (Blondel, et al., 2012).

A team from International Business Machines Corporation (IBM) took on the challenge to process the data to analyse the mobility within Abidjan, and eventually to improve the situation. The data showed from which phone antenna a call or text message was sent or received and at what date and time that happened. The data was studied to reveal patterns in behaviour that could help analyse directions of travel. Additionally, data about the formal public transportation routes of Abidjan, SOTRA buses, was used to map out the bus routes and their bus stops, for this the open-data platform 'Open Street Maps' was used. The two compiled datasets were then combined to visualize the direction and frequency of commutes in Abidjan (Di Lorenzo, et al., 2016).

After being able to visualize the mobility patterns in the city, an interface was created named 'AllAboard'. The interface was made with the intention for it to be used by the local authorities in Abidjan to analyse the travel demand in the city. The interface allowed for the selection of several filters to tackle specific locations, travel flows, travel times and much more types of information. With this information, local authorities can adjust the provided public transportation to improve the quality for its inhabitants (Berlingerio, et al., n.d.). With use of the AllAboard platform, over 60 potential proposals were made by the IBM team to improve the existing system of SOTRA buses. The most effective proposal would reduce travel times by 10 percent for certain users of the bus system (Talbot, 2013).

5.2. Summary of Case Studies Framework Findings

Using the case studies from the previous section, a framework has been compiled (Attachment 1). The framework revealed patterns and assumptions that could be made by compared the different cases. This section aims to summarise the findings.

In all cases, similar initial problems were present in the cities. The most apparent similarity was that all the cities suffered from travel congestion. This was caused by the present road infrastructure not being able to accommodate the rapidly growing populations of the city and their commutes. As well as the traffic not being managed due to a lack of reliable information available about mobility patterns. Consequently, this has led to commutes having a longer duration in these cities. To combat these problems, by implementing

interventions and policies that are evidence-based, a reliable stream of data was required that could be used to analyse mobility patterns in the cities. However, for these cities in developing countries, the use of traditional sources such as surveys to gather data, was financially unattainable or would take too long to achieve results. These problems were the leading factors that sparked the initiation of projects to process and analyse data collected through innovative sources.

To retrieve, process and analyse data through innovative sources, public actors collaborated with several types of private actors in all the cases. The public actors concerned with such projects were usually local authorities in charge of the mobility situations in the cities. Actors such as ministries of transportation, but also on a smaller scale such as governmental organisations operating public transportation connections.

The types of private actors involved differed in each case, ranging from mobile service providers to international institutions. Although the private actors differed in form, the duties they executed were similar throughout most cases. They provided insights on how to set up the projects and which types of data could be gathered from which sources. Furthermore, they provided analysis and software to interpret the delivered information. In some cases, data was provided for free by certain public actors and some parties offered financial aid for the project.

The collaboration of public and private actors contributed to the success of the projects. The private actors provided their expertise and guidance to aid the public actors in reaching their goals.

There was one exception to the standard distribution of roles of public and private actors, in the case of Nairobi. There the local inhabitants were involved as public actors and took on tasks of collecting and uploading data to an open platform.

The main innovative source from where the data was gathered in all the cases was through mobile phones of inhabitants. The most common data that was extracted through mobile phone usage was GPS data that was transmitted from the devices. The GPS data provided information about the locations of users during their commutes and allowed to portray travel directions and calculate travel times.

Alternatively, in cases where GPS data was not extracted from mobile phones, data from phone transactions from calls and messages were used. The Call Detail Records (CDR) provided time stamps of phone transactions and an approximate location by determining the antennas that transferred the transactions. This provided information on the commutes of mobile phone users such as their location, direction of travel and the duration of travel.

In the different cases, either mobile GPS data or CDR data was the main source of data. Both types of data were complemented with several other types of data such GIS data to identify different types of roads, by uploads of user data such as occupancy, and with existing databases that provided public transportation routes and bus stop locations. The combination of the different types of data provided a better understanding of the mobility data and patterns in the cases.

For the collected data to reveal insights on the mobility patterns, the data had to be processed. In all cases a platform or software was created that allowed for the data to be visualised and analysed. These platforms contained all the data that was gathered and used it to show real-time travel patterns, where the most congestion occurs and the duration of

commutes. This created a clear overview of almost all the commutes taking place within the cities. The platforms and software were created by the private actors, to be used by the public actors. It provided public actors such as the local authorities with insights that were previously unavailable to them.

With the possibility for public actors to be able to visualise and understand the mobility patterns in the cities, allowed them to be able to tackle problems where it was most needed. In all cases this resulted in a reduction of travel times, by implementing solutions for the most congested locations, and by providing better access to the forms of public transportation to meet the needs of inhabitants.

5.3. Thematic Literature Review

5.3.1. Types of Traditional Sources for Mobility Data

Having a system of managing traffic based on data allows for an efficient flow of traffic. It reduces the amount of traffic jams and the duration of trips. A well-built system could reallocate the volume of cars on roads by promoting the usage of transportation methods that aren't being fully utilised. Furthermore, it is beneficial to have an accurate overview and accurate data of all modes of transportation present within a city, this allows for more efficient traffic management by maximising the potential of all modes (Lang, et al., 2020). Yatskiv, Grakovski, & Yurshevich (2013) state that policy makers face the challenge of implementing decisions that can improve mobility in urbanized areas. The authors concur that for such solutions to be effective, reliable data concerning traffic and accessibility to transportation are required to create a positive impact on mobility. Mobility data that is collected can be analysed to provide insights on factors such as why and how city dwellers travel, the duration of their commute, where and how congestion occurs, travel directions and several other relevant information. Several traditional techniques have and are still being used to acquire such data.

Cvetek, Muštra, Jelušic, & Tišljaric (2021) also mention that it is of importance for urban planners to have a reliable flow of data concerning traffic. It is required to understand the formation of congestion in urban areas to subsequently attempt to minimise the levels of congestion. Repeated occurrences of congestion signal that in certain areas, the capacity of roads cannot keep up with the number of vehicles making use of the road, consequently leading to delays. Noting that increased levels of congestion lead to a deterioration of liveability for urban dwellers. The authors mention the use of various traditional traffic sensors as a method to generate data, in order to measure the flow of traffic and to predict patterns of congestion. Sensors can be deployed alongside roads or at intersections, where they can generate data from a fixed location. Different sensors provide different types of data, such as the number of vehicles passing by, the speed at which the vehicles are driving and how much of a road's capacity is available. Overall, traffic sensors can provide a reliable flow of data in real-time, but they are restricted to a fixed location and have high installation and upkeep costs.

Travel surveys are another form of a traditional method of collecting data that provide understandings of mobility situations. Commonly used surveys are the Household Travel Surveys (HTS), these surveys are distributed among several households at random, these may be time consuming because the answers must be checked for validity and a follow-up may be required. Other types of surveys are held in person in an interview manner, this is an expensive method because it requires travel and labour (Griffiths, Richardson, & Lee-Gosselin, 2000).

By carrying out surveys, information could be retrieved that could complement the available data. Surveys could be automated through an online platform or could be manually distributed and collected by people. Surveys could serve different purposes to gain specific information. They could target a certain mode of travel, a particular area (TUDelft, n.d.). Pticina (2011) supplements that surveys could provide data on the quality of mobility and services, based on experiences of users, in this case the experience of users of public transportation. These types of surveys indicate information such as the purpose of commute but also how users experience the convenience of available (public) transportation methods. This reveals to urban planners which aspects could be improved. Furthermore, data could be acquired from transport operators, through databases that keep track of usage of the transportation mode, but also other relevant data such as schedules, prices, and route-maps.

Using surveys in developing countries is not an optimal option. Mobility data is usually already insufficient, surveys could not cope with filling the missing data. They also don't provide options to be able to map out travel routes. Further weaknesses of surveys are that they consume time to collect data from, and can only be held every few years, this means that most data are not relevant by the time it is analysed. Another reason is that they only focus on a small portion of a population, which results in an unreliable depiction of reality. Also, they are filled in by people and can therefore include mistakes (Dalberg Data Insights, 2018).

The different types of traditional sources for mobility data are summarised in the table below.

Type of traditional source	**Opportunities**	**Barriers**
Traffic sensors	- Provide vehicle count - Provide traffic speeds - Provide road capacity indication	- Fixed to a specific location - High installation costs - High maintenance costs - Requires skilled personnel.
Travel surveys	- Provides complementary data (social, demographic etc.) - Could target specific mode of travel - Provides reasons and motivations for commutes - Provides opinions on satisfaction of commuters.	- Expensive - Time-consuming - Limited to sample.
Databases	- Provides social and demographic information - Provides public transportation routes, schedules and fares	- Requires access to information, may be owned by private organisations.

5.3.2. Use of Innovative Sources for Mobility Data

Data about the mobility of people, can also be generated by inhabitants of a city or by private organisations. Specifically, data that includes their location and when their commute took place. Such data can be retrieved via phone applications, companies that provide transportation options like taxis and telecom providers. Users of mobile phones are continuously generating data while using applications that contain details about their whereabouts and where they are moving to (Ahlers, et al., 2018).

Barkham, Bokhari, & Saiz (2018) strengthen that innovative data sources include data that is collecting through mobile applications where for instance inhabitants, such as users of public transportation, could upload relevant real-time information during their commute such as delays. This is a form of crowdsourcing, as inhabitants take the initiative to voluntarily help in uploading data. Another manner is data that is in the hands of private organisations, such as social media companies and telecom providers. Such organisations usually have a vast amount of data generated by their inhabitants, simply by making use of their service. This could allow for the analysis of behaviour to predict patterns in mobility flows.

Sobková, Čerticky, & Jiráček (2019) confirm that a large flow of data is being generated by the use of mobile phones, through applications. If this type of data is managed properly, it can be beneficial for policy makers to make decisions. This is especially the case for organising traffic flows in a city. Traditional methods of analysing traffic patterns are bound to high costs. While data generated from innovative sources such as mobile phones, if customised to extract the required data, could provide more reliable data such as specific directions and times.

The rate of urbanization of many cities around the world is increasing the need for reliable mobility data. Mobility data from innovative sources will assist urban planners to implement effective policies that are based on evidence. Data can be acquired in large quantities through smart systems, to gain real-time big data that can be analysed for traffic patterns. This will help control the flow of traffic in cities and plan the city in a manner that mitigates congestion. Furthermore, it will help with distribution of money to areas where it is most needed (Silver Touch Technologies Ltd., 2020).

Also supporting this idea are Barkham, Bokhari, & Saiz (2018), saying that the use of innovative data to analyse mobility patterns could provide improvements in mobility for inhabitants of cities in developing countries. It could be collected to deliver information about public transportation, such as locations it can be accessed and times. This can be achieved by uploading data from smart phones regarding information on public transportation routes. It could also be used to reduce congestion in places where it repeatedly occurs. This can be done by analysing traffic flows with data attained from mobile phones, to predict where congestion occurs and eventually implement a solution for the problem. Alternatively, the tracking of mobile phones through call records could be used to provide data about the speed at which travel moves and the capacity of roads and modes of transportation.

Local governments in developing countries could be motivated to use innovative data sources to improve the manner in which services such as public transportation are managed in a city. It could aid in making mobility more efficient while simultaneously cutting down on costs. Local governments may see it as an option to improve predictions on mobility patterns. This eventually leads to providing urban dwellers an improved well-being as it has the potential to increase their mobility and therefore save time and become more

productive. Especially for developing countries who are already facing urgent issues. By obtaining a reliable data stream, they could skip a step in developing and implementing traditional costly methods. This allows local governments to prioritise real-time issues and development of infrastructure (Ying Tan & Taelihagh, 2020). Traditional methods of mobility data collection are limited, they offer a relatively small sample of data that is fixed to certain times and areas. This makes the use of mobility data through innovative sources attractive for developing countries (Sinha, Vidushi, Rakesh, & Abraham, n.d.).

The use of innovative data source is more efficient in terms of costs, time and volume of the data that can be attained, as opposed to traditional methods of generating data like surveys. Eventually governments all over the world will make the transition to using innovative data sources for urban planning. It has the potential to significantly improve the wellbeing of a city's inhabitants, by local governments using the data to implement creative policies (Barkham, Bokhari, & Saiz, 2018).

5.3.3. Benefits

Informal transport makes up a large portion of public transportation in developing countries. Informal transport in developing countries should not be neglected, it should be seen as a crucial part of the mobility within a city because it is an important part of dwellers' commutes, especially poorer communities. They often provide accessibility to areas that are otherwise inaccessible by (formal) public transportation. However, due to its informal nature, there is usually insufficient data available about the service. By using innovative sources of data, the quality of the informal service provided could be improved. This can be achieved by using the data to provide real-time information to inhabitants. Information such as routes, bus stops, departure times and arrival times. This could provide a thorough depiction of all the transportation networks that are present in a city, for both the local authorities and the inhabitants. The use of innovative data sources could provide information that can allow the developing of smartphone applications about transportation options in a city, creating ease for the inhabitants when picking the most suitable mode of transportation. Furthermore, innovative sources of data could assist with the efficient planning of routes, this could shorten travel times (International Transport Forum, 2019).

The usage of mobile data could allow for the visibility of all transport modes in a city. This information can be combined in a single information access point, to reveal all the available modes of transportation to reach a destination from the commuter's location. Sharing of data from innovative sources could also increase road safety. If information about accidents could be directly sent by users of mobile phones, emergency respondents could act quicker. Patterns of accidents could be recognised by analysis to reduce future accidents in particular areas (NITI Aayog & Rocky Mountain Institute, 2018).

Sinha, Vidushi, Rakesh, & Abraham (n.d.) also sum up numerous ways that innovative sources of data could benefit cities in developing countries:

- The use of technology for data allows for a more efficient distribution of resources, allowing authorities to assess where resources are needed the most. This could also reduce consumption of resources and costs of projects.
- Innovative platforms allow inhabitants to access and send information without having to be physically present at a certain location.
- Tracking of vehicles can be achieved through GPS sensors or through smart phone applications, of which trip information could be shared.

- Call data records could be used to identify people's commutes.
- Increases the reliability of transportation of the city, it may reduce the time travellers have to wait and increase access to transportation.
- Reducing of congestion because routes can be optimised depending on the data.
- It could provide mobility solutions for specific commuters, whom have the least access to transportation.

5.3.4. Collaborations

Cities in developing countries may have a limited number of resources that can be used to improve existing structures and patterns. By collaborating with international organisations, a possibility can exist to retrieve data that is directly collected from inhabitants at a low cost. Making it affordable to implement solutions that are based on empirical evidence (The World Bank Group, 2016).

Collaborations between public sectors and private organisations to generate data from innovative sources, have the potential to implement creative solutions to common problems in cities such as congestion. Several different types of stakeholders could become involved in the process. Stakeholders such as financial institutions, educational institutions, software developers and inhabitants of the city (World Economic Forum, 2020).

Vasilescu (2019), a policy expert of the UNDP in Moldova, suggests that for developing countries with a lack of information about mobility patterns and restricted resources, can benefit from innovative sources of data. This data that could be provided from collaborations with private organisations such as telecom providers. Collaborations for innovative data could provide local governments with an opportunity to map out the mobility patterns in a city. Also, it can provide insights on how and why inhabitants commute, complemented with additional information about commuters. In turn, this could benefit local authorities to improve existing infrastructure and services such as public transportation.

Collaborations between public and private sectors could ease setting-up and the usage of data platforms. It could benefit both involved stakeholders if the intended results can be achieved (Roy Chowdhury, et al., 2017).

By involving different stakeholders for cooperation in solving problems. Local governments could share the burden of making decisions, it allows for a more inclusive approach, that can benefit more people and organisations. Another motivation is that by including poorer communities in the data generating phase, it can ultimately allow this population's well-being to improve (Ying Tan & Taelihagh, 2020).

NITI Aayog & Rocky Mountain Institute (2018) identifies different types of stakeholders. The companies that collect and own the data produced through innovative sources, such as telecommunication providers, this data is generated by users of their services. Another type of stakeholders are organisations and individuals that could benefit from the data, this could include companies that use the data to generate income from their services. It could also be local authorities with the aim to improve mobility. Both private organisations and local authorities could use the data to benefit commuters, by improving a service using the data. Therefore, commuters are also stakeholders. There are also government institutions as a type of stakeholders, in particular when they are owners of data. Usually, this data is provided to the public as open data.

GSMA (2011) states that providers of telecommunication services have qualities that could make them valuable for collaborations for mobility data. These types of private organisation already have strong existing networks. Due to their accessibility and availability, they have a large reach over most populations. Telecommunication providers already own real-time information about their users and know how to process it. Furthermore, they are organisations that know how to deal with privacy of users and how to ensure that data is safe.

5.3.5. Opportunities

In many developing cities around the world there is a massive amount of data in circulation, such as through smartphones and sensors on vehicles. If this data could be captured, it could be harnessed to produce invaluable information to be able to analyse mobility patterns in cities. These types of data could generate real-time information regarding traffic details, such as congestion and incidents. With this information, commuters could be diverted away from these locations (Sustainable Mobility for All, 2021).
The number of mobile phone users in developing countries is rapidly increasing and is expected to continue in this trend. This means that data from these innovative sources can be collected from a large portion of a city's population (Pokhriyal, Dong, & Govindaraju, 2015).

Mobile phones are highly accessible by most populations, they provide data from users to urban planners with ease and directly. This makes it easier for governments to tackle specific matters. Another opportunity is by making the data available as open data, it can then be accessed by anyone. This allows the opportunity for different parties to analyse the data, it could provide different approaches to analyse the data that may have been overlooked. It would also save time of analysing the data because multiple actors will be involved. Furthermore, if a project can be proven to be successful at low costs, such as by implementing a pilot study, it could gather support from more stakeholders. When more stakeholders eventually believe in the impact, such projects could be performed on a larger scale. Gaining more support from different stakeholders could make future projects more efficient and effective (Roy Chowdhury, et al., 2017).

Collaborating and including different stakeholders in projects, could assist local governments with the financing of projects. If improving the mobility could lead to generation of income, for instance for transportation operators, they may be more willing to invest in the project. Also, if inhabitants of a city understand how a project may improve their well-being, they may be more willing to aid in the generating of data voluntarily through crowdsourcing (Ying Tan & Taelihagh, 2020).

The use of innovative sources of data has the opportunity of providing solutions for developing countries that are highly effective at a relatively low cost.

Moreover, by improving mobility aspects within a city, ensures that the city is prepared for future opportunities. These could be new businesses that require an affordable and accessible mobility infrastructure. This could benefit a city from an economic aspect by generating more income and increasing work opportunities.

Also, working with innovative sources of data in developing countries, could lead towards more cooperation between developing countries. They may see the impact of

implementations and use it as a source of inspiration in their own country. This leads to a chain reaction of positive change for developing countries (International Transport Forum, 2019).

By knowing how to utilise mobility data from innovative sources, it opens the opportunity to use advanced technologies in the future. Such as by using Artificial Intelligence (AI) solutions to automate the monitoring and controlling of traffic.
Another example is allowing for new modes of transportation that rely on a reliable flow of mobility data and use smartphone applications to optimise their service.
By providing open data, that can be accessed by the public, it increases the chance for collaborations and allows for improved analysis of the data (NITI Aayog & Rocky Mountain Institute, 2018).

Private organisations that specialise in technology services are available for partnerships with local authorities, to create custom solutions using innovative data sources. These types of private organisations could provide technologies that could collect and analyse mobility data. Guiding local authorities to find a suitable solution to their problems.
Alternatively, setting up open data platforms could provide a cheap alternative to collaborations between private organisations and local governments. It allows for data to be accessed publicly, this provides the opportunity for local researchers and developers to analyse the data and propose solutions (United Nations Human Settlements Programme (UN-Habitat), 2020).

5.3.6. Challenges and Barriers

Certain challenges could come with the use of innovative sources for mobility data. Local governments should be open to the idea of sharing data, for this to happen they have to realise that collecting such data could be of value. Local governments often do not know how the data could be of use to them. For this it is required for them to collaborate with private organisations that could develop software or a platform to be able to analyse the data, also a platform for inhabitants to be able to upload open data may be required. Such collaborations could come at a cost, so local governments may have to be educated in the benefits a collaboration may reap.

Another issue may be the usability of the data, merely having a platform to upload data too is not sufficient. The generated data has to be organised and filtered to be able to extract the valuable information that is within.
There is a danger that open data, data that is accessible to everyone, may be abused by people to achieve other goals. The purpose of the data should be intended to achieve 'social good' and should protect all classes of people instead of increase inequalities.
Privacy may also pose a challenge when dealing with data that is gathered from individual's behaviour. The data should be processed in a manner where the identity of people cannot be traced back to them. Additionally, national laws should not prevent the sharing of data, but should be adapted to sharing in a responsible manner that still protects the privacy of individuals.

When it comes to using innovative data sources, there is not a solution that fits every city. Every city has its unique situation and problems. The generation of data through innovative sources should therefore be tailored to meet the city's specific needs (Barkham, Bokhari, & Saiz, 2018).

Data generated from innovative sources usually comes in relatively large volumes, as compared to traditional methods of data collection. Data could be obtained from multiple different sources such as mobile phones, camera images and software. Each type of source could also provide various sets of data. It may be an arduous task to combine different types of data in a manner that allows all the different types of data to be compared with one another. This is however of importance to be able to conduct analysis using several data types. Additionally, it can be difficult to find an effective approach in gathering and using data from innovative sources. Projects have to be carefully planned so that the collection of data can be used to make an impact (Lang, et al., 2020).

Challenges may arise around data sharing due to the privacy and ethics of sharing the data. Another challenge is that transportation operators may be unwilling to share their data. They may fear that by sharing the data. It provides information on how they generate income. Sharing the data could affect them financially, as it may divert passengers from using their services or they might have to charge less for fares in the future. Owners of mobility data may value their data at a high value, based on their revenue. Meaning they may not be willing to provide their data for free (Sustainable Mobility for All, 2021).

NITI Aayog & Rocky Mountain Institute (2018) adds to privacy concerns. Privacy laws are required to protect the identity of users, without precautions, the data could be traced back to an individual's identity. This may cause harm if the data is not stored securely. It is however possible to remove personal identifiers from data, while still remaining useful for analysis.

Laws may also work against the sharing of data. It is often the case that national laws may prevent the sharing of mobile phone generated data due to the privacy of users. Data that is generated through this means is personal and may be linked to a person and their activities or affiliations. This can be solved by enforcing new laws.

Another challenge may be that for data generated by mobile phones to be operable, it has to be convertible into a format that can be processed for analysis. Also, the amount of data collected has to be restricted to remain achievable, if for instance data is collected every minute from millions of users, it could result in a data that is too large to share and be processed for analysis.

Finally, ownership rights of data may pose as a barrier to obtain it, if the data is not easily accessed due to restrictions, it cannot be used to analyse mobility patterns (Ahlers, et al., 2018).

Arora (2016) mentions other types of challenges that may arise. To be able to help the urban poor, data must be collected from them. This data should not be part of a marketing scheme that could eventually exploit the poor and increase inequalities.
For crowdsourcing to take place, a diversity of population groups would be preferrable. Such as the inclusion of the urban poor in the process. To include the urban poor, they have to be convinced and have faith that their government will use the data to improve their well-being.
International Transport Forum (2019) comments that a cities network infrastructure may also be a challenge. Inhabitants must have access to internet networks to be able to collect

data from their phone. This could be a barrier for poorer communities as they may not own or have access to a mobile phone with/or an internet connection.

NITI Aayog & Rocky Mountain Institute (2018) confirms that network infrastructures are of importance. Collected data may be of reduced quality if datasets don't provide information that is accurate. To ensure that data is accurate, innovative sources such as GPS systems should be well maintained. Mobile users should also have access to reliable connections so that data collection is not interrupted.
The author also agrees that private organisations that own data may be unwilling to share their data. They fear it may have negative consequences for their revenue. To address this issue, it is required that it is well-defined for what purpose the data will be shared, also how it could benefit the private organisation to share their data.

The United Nations Human Settlements Programme (UN-Habitat) (2020) provides another example of challenges from lack of reliable networks. Technology companies are distributed unequally over the world. The majority of such companies reside in developed countries. As a result, developing countries are lagging behind from a technological perspective. This may require an initial investment to develop a technological infrastructure before being able to use innovative sources for data.
Due to this, inhabitants of cities in developing countries may not have access to equipment like mobile phones with an internet connection.

The author also emphasises that regulations have to be set in place that manage how innovative sources of data can be used. If the intention is to improve mobility situations, local governments should be cautious that the usage of such data does not cause the unintended. For example, the availability of mobility data could be attractive for on-demand ride hailing companies, that could lead to more congestion.

5.3.7. Requirements

There a several requirements that could play a role in the level of success in achieving an improved mobility. Governments and private organisations should have clear goals in what they would like to achieve, preferably goals that are measurable.
Creative solutions often require new methods for analysing and modelling of mobility data, this usually means that a willingness to invest in new methodologies should be present.
From both governments and private organisations there should be an organised manner of governance to tackle mobility problems in a city, so approaches should be structured to achieve the intended results without compromising efficiency.
Collaborations between local governments and private organisations is a key factor in ensuring the success of a project. The different stakeholders each have a different set of skills, to fully optimise these skills, cooperation is required between the different stakeholders, with clear goals and a mutual agreement on the outcomes (Lang, et al., 2020).

Regulations have to be realized and enforced to make sure that data from innovative sources can be used. Regulations that are transparent about how the data will be used and what the intentions of data collection are. These regulations entail matters such as privacy, where there need to be strict laws about how data is shared and used. Also, matters such as who owns the data and who can access it need to be clearly determined. To enforce these laws, there need to be clear consequences to abuse of data. By achieving a well-regulated data collection system, inhabitants will be ensured that their personal data is safe, this may

increase their willingness to partake in activities such as crowdsourcing. Regulations may also protect private organisations and increase their willingness to invest in projects.

Another requirement is a well-maintained technology infrastructure for the collection of data via innovative sources. Inhabitants of the city should have access to network services such as internet and telecommunication lines. If such services are not present in the city, collecting data through innovative sources will not be attainable.

Furthermore, city governments should have educated people, experts in the field of mobility, that can analyse and interpret the data. Without the understanding of the data, the data is of little use. Private organisations could aid in the analysis and educating of people to understand the data (Ying Tan & Taelihagh, 2020).

Sustainable Mobility for All (2021) also states that clear regulations should be defined with regards to sharing data through collaborations of stakeholders. For example, when there is a collaboration between the public and private sectors, to clearly define which data can be shared and the intentions of the data. So that the data is not misused for other goals.

Another requirement is creating common goals between stakeholders, goals that benefit the different stakeholders in a just manner.

Finally, the author mentions to not compromise the privacy of inhabitants, extract only the data that is required to achieve the intended outcomes. Also, by specifying from where and how the data can be captured.

The International Transport Forum (2019) describes alternative requirements to enhance the use of innovative data sources. Regulations should be up to date with the technologies that could be used to provide mobility data. If this is not the case, it could slow down the development of using such data because the regulations do not permit thee use such data yet.

Additionally, there should be cooperation between different levels of government, this allows for projects to be supported across other sectors in order to fully benefit a complete system.

The use of innovative sources should not be restricted to a certain path by government regulations, this is because every problem requires a unique solution. However, the use of innovative data sources should mainly focus on improving existing infrastructure and transportation modes, instead of being limited to the introduction of new systems

Another requirement that may be applicable for developing countries is that local governments have to be willing to collect and share data on all forms of transport in the city, including informal modes of transportation. This means that local governments also have to acknowledge these informal modes, and not deny them to protect their political reputations (Williams, White, Waiganjo, Orwa, & Klopp, 2015).

6. Discussion

6.1. What type of data is there to solve mobility problems, and what type of innovative data?

To solve mobility problems, a flow of reliable and relevant data is required about the mobility systems. Mobility data can be analysed to provide access about why and how situations occur. The literature review identified several forms of data collection through traditional methods and equipment. Sensors could be placed at areas of which data is to be collected, in the case of mobility, it is where commuting occurs. These commutes could be of any mode of transportation such as walking or public transportation networks, at these locations sensors could be placed. Sensors can provide real-time information about mobility systems, but they are usually expensive to install and to maintain. They are also fixed to a specific location, restricting the collected data to the areas they are installed in. To cover a whole city would require a vast investment. Also, they are not very versatile in terms of the various different types of data they can collect. They could provide analysis about traffic but not about specific population groups.

Another traditional method of collecting data is surveys, this form of data collection can provide information about specific population groups and their experiences with mobility. This provides urban planners with qualitative data, that may be limited for visualizations. They are not as reliable as other methods because they may include mistakes. They are also limited to a relatively small sample, so they do not offer a complete image of all commutes in a city. To deploy them is both time and money consuming, furthermore the data obtained from them may be irrelevant by the time a policy is implemented because they do not offer real-time data.

Lastly, the method of collecting data from existing databases, such as those of transportation operators. Data can be collected about 'fixed' information such as schedules and fares. These could be used as indicators for mobility patterns or could supplement analysis of other forms of data.

Several case studies reflected upon the findings from the desk research. In the case of Kampala, the collection of data through surveys was not viable for the city because it would be too costly and time consuming. A different kind of approach was needed.

In the case of Manila, traffic sensors were not a feasible option because they would require high investments and technical staff, that are educated to install and maintain the sensors. Additionally, the local government was missing data on most commutes, sensors would have to be deployed all over the city to attain reliable data.

In Abidjan, to supplement the data that was retrieved through records of phone transactions. Data was collected from the public transportation line of buses, containing maps of routes and bus stops.

Both the literature review and the case studies revealed several types of innovative data and methods to collect it. Most of the innovative data came directly from dwellers and it was always real-time data. It is often collected from mobile phones of dwellers. Attaining data from mobile phones happen eithers by dwellers interacting with applications or transactions such as calls, or by crowdsourcing, where dwellers could voluntarily upload data. By data collecting through usage of mobile phones, data such as GPS locations, the time, location of phone call and more. This was the case in Lima, whereby collecting this data provided information about duration, direction and purpose of trips. In Nairobi, GPS data from mobile phones was used to map bus routes. Also in Kampala, data was retrieved

from mobile phones that showed from where-to-where commutes took place. Abidjan made use of call records to triangulate through phone antennas where commuters are. While in Metro Manila, GPS data was also collected from mobile phones.

The other method of crowdsourcing was also utilised in the case studies. Specifically in Nairobi and Metro Manila, open data platforms were set up to allow inhabitants to voluntarily upload real-time traffic information.

The retrieved data often needs to be converted into data that can be processed. Such as was the case in Nairobi, where the GPS information was converted to a format called GTFS to be able to upload it to Google Maps. This makes data readable by smartphone application users. The mentioned methods do not require expensive investments, as the data is already in circulation through usage of mobile phones. It is only required to gain access to that data and create a platform and/or software to process the data.

The case studies framework showed a pattern in the usage of both traditional and innovative sources to solve mobility problems. Innovative sources in the cases, GPS and CDR data, were collected from mobile phones of inhabitants, to serve as the primary source of data. These types of data were collected as an alternative to expensive traditional methods of collecting data through traffic sensors and surveys. However, the innovative sources were still always complemented with other types of traditional data. This was in the form of data from databases that provided fixed information, such as social and demographic information of mobile phone users, but also existing public transportation schedules from operators. By doing so, a complete understanding of the mobility pattern could be unveiled at relatively low costs, as opposed to only using traditional sources of mobility data.

6.2. How can local governments and private organisations collaborate to generate innovative sources of data?

Cities in developing countries are not always equipped with the knowledge and resources to be able to experiment with new projects. Partnerships can provide guidance through insights from experts and can relieve a portion of the financial and decision-making burdens. As mentioned before, mobility data through innovative data is already in circulation. However, to utilise it, it has to be accessed and processed. Collaborations could lend a helping hand with such matters. These collaborations are between local governments, such as urban planning and transportation departments, that are concerned with improving mobility in local cities. Together with private organisations, that either have access to data or know how to process it. Typically, there are stakeholders that have access to data, stakeholders that know how to process the data for improving mobility and stakeholders that can benefit from the data. Owners of data are usually private organisations that offer services in the city, such as telecommunication providers and transportation providers. In almost all cases, the beneficiaries are the inhabitants of which the mobility service is to be improved, but it could also include public transportation providers that can optimise their networks. Stakeholders that know how to process the data are usually developers of software and tools, this could be private organisations but could also be community based.

In Lima the local authority of transport, collaborated with an organisation named ‘LUCA’. This organisation was able to benefit the local authority in two ways, firstly by providing the data through their head-organisation ‘Telefonica’, that has access to mobile

data from users. Secondly, they were also able to analyse the data for them. This provided an opportunity to gain valuable data at a relatively low cost, compared to traditional methods.

In Kampala, Metro Manila and Abidjan, a similar approach was taken, but it involved more stakeholders. Each stakeholder had their specific expertise to optimise the data collection and the data analysis efficiently. However, in Abidjan, the local authorities were presented with a tool by private organisations, without initiating or partaking in the project themselves.

The case in Nairobi was particularly different to the other cases. There the initiative did not include the local authorities at first. Instead, the project was started by a local university, with several private organisations. Together the stakeholders collected data to map out bus routes. Also, an open data platform was set up, this allowed for data to be crowdsourced, by inhabitants uploading their data to the platform. A result of the crowdsourcing was the development of a smartphone application, produced by local developers. Even though the local authority was not directly involved in the project, they have realised the benefits it provides. The local authorities use the open data platform to perform analysis.

It is of importance that local governments have knowledge about how innovative sources of mobility data could benefit their specific needs. This research has shown that by collaborating with different stakeholders, results could be achieved that were once unattainable for a country with limited resources. Local governments must be willing to cooperate with such stakeholders. For a successful collaboration to happen, there should be cooperation within the different levels of government, so that it is clear what the goals are and to ensure the project does not fall apart. When clear goals are set that all stakeholders agree upon, that is when the most success is achieved. Also, for a successful collaboration, local governments have to be transparent and open to improve mobility in an efficient manner. So, they must be willing to collect and share data on informal transportation. It is not always possible to implement new transportation systems and neglect existing ones.

The case studies framework showed that in all the cases there was a form of collaboration between public and private actors. For local authorities in developing countries, it is crucial for the success of the project to involve private organisations. Private organisations allowed for the data to become accessible and usable.

Ultimately, local authorities in developing countries are often not capable of collecting data through innovative sources without the help of private organisations. Private organisations have the knowledge, experience and access to be able to collect and process the mobility data. It could occur such as in Nairobi, that the local authorities are not involved in the process initially, but it is unlikely for the project to be successful without involvement of private organisations. Private organisations will require financial compensation for their services and involvement, which may have to come from local authorities.

There is a lot to plan for before starting a project to collect innovative sources of data. There are several requirements to be met by local governments of developing countries. A government that wants to achieve social good for its inhabitants, can achieve these requirements with help from collaborations. Various opportunities may come forward

that can ease projects in motion and increase the chance for increased development in the future.

6.3. How can local governments of cities in developing countries implement mobility solutions using innovative sources of data, and how effective are these solutions in improving urban mobility?

Innovative sources of data provide several benefits that could aid urban planners to implement mobility solutions. Data that is acquired through means of innovative sources often provide a complete image a city's mobility capacity and infrastructure. This includes commutes taking place through informal means of transportation. Informal transportation dominates in most developing countries, with many people depending on it. Local governments rarely have adequate data about informal forms of transportation.

The data gathered through innovative sources can allow patterns to be recognized and to determine where interventions are needed the most. Since resources are limited, especially in developing countries, the use of innovative data allows resources to be allocated efficiently. This allows for evidence-based interventions, where the evidence comes from the mobility data retrieved from innovative sources. Real-time information about congestion and accidents means that local governments could act faster.

There are several challenges and requirements for local authorities of developing countries to be able to attain mobility data through innovative sources. The infrastructural environment in a city may determine how successful the collection and processing of data can be.

To be able to acquire mobility data through innovative sources, technological infrastructure networks must be available to inhabitants of the city. If only a small portion of a city's population has access to a mobile phone or internet, the amount of data collected will be limited and it will not provide a reliable depiction of situations. The cases reviewed in this research all had a relatively high number of mobile phone users, this allowed for an accurate reflection of mobility situations in analysis. Solely having data being generated is not sufficient, it is required that there is a platform to process the data, and that there is an understanding of the data. This may require staff of local authorities to be educated. In the case study of Lima showed that collaborations may support this, by private organisations teaching local authorities how to interpret and use mobility data.

To ensure correct and ethical use of data, laws may have to be implemented. Specifically, privacy laws that could determine how data can be shared and with who. The use of data that is gathered directly from inhabitants holds personal information about the users. The identities of users should not be traced back to them, as not to cause them harm with sensitive information. In the case of Abidjan, where call data records were used, the identity of the users was cleared, making it impossible to trace back who the data came from. Regulations may also matter when collecting data from innovative sources. Sometimes data has a specific owner, such as telecommunication providers, in that case data cannot be collected unless the data owner gives permission. Another reason why collaborations could be of importance. With clear goals set on how the data is used, data owners may have to be persuaded that sharing the data could benefit them, instead of harm their business.

There are also opportunities that may facilitate using innovative sources of data and make it feasible for cities in developing countries. If a city can launch a successful project of collecting mobility data through innovative sources. More stakeholders will see the benefits of such a project, this will increase the ease of initiating new projects. As a result, inhabitants will also be more willing to partake in future events. Also, by having reliable mobility data present in a city, there are more opportunities for development and new services. This was both the case in Nairobi and Metro Manila. In Nairobi, the local authorities realised the benefits after an impact was made. They are now willing to launch similar projects and use the data to plan new interventions. While the project in Metro Manila was based on a successful pilot in Cebu City, making it possible for them to implement it on a larger scale.

Impacts of using data from innovative sources, to improve mobility situations, were observed in the case studies of this research. In Lima, the collection and analysis of data from innovative sources allowed for travel patterns to be predicted. The data was from different modes of commutes within the city, that represented most of the transportation in the city. By knowing from where inhabitants travel and by identifying where the missing links in the transport network were. The local metro authority was able to optimize the networks to make the metro mode of transportation more accessible. With the new information they were able to plan where to build their next metro stations to limit overcrowded metros and increase ease of commuting for inhabitants. Travel times between certain points in the city have been able to be reduced as well, due to better placed stations and ensuring the need for transfers is less. They have also been able to adapt their departure schedules to better fit the demand of the inhabitants. For a portion of the population, it means the commute to work takes less time. Furthermore, the increased connectivity and accessibility ensures that there is less congestion on the roads in the city, as more people use the metro.

In Nairobi, there were also several impacts from the use of innovative sources of data. By being able to map the bus routes of one of the most used modes of transportation, also by providing real-time information to inhabitants about delays and incidents. This increased ease of commuting for inhabitants as they could easily identify which bus route they had to take to get to a certain location. It also allowed for them to avoid areas that are congested. This reduces travel times for commuters and results in a more even distribution over the city's infrastructure. Another benefit of having the informal bus routes mapped out, is that it is used to optimally plan for a formal bus as public transportation. Ultimately improving the city's connectivity and accessibility.

In the remaining cases of Kampala, Metro Manila and Abidjan, the use of innovative sources for mobility data also provided real-time information. With this information, local authorities were able to determine bottlenecks in the road infrastructure and implement interventions for these areas. The tool used in Abidjan, was able to propose solutions that could reduce travel times for public buses, by up to 10 percent in specific areas.

The case studies framework showed that in all cases data was gathered through an innovative source. Specifically, GPS and call detail records were collected from mobile phones. To ensure the data provides optimal results, it was combined with a secondary set of background data from databases and registrations. This data together allowed for an accurate and reliable flow of information about mobility patterns in the cities. The local

authorities in the cases were all able to use the data for analysis and to provide solutions based on evidence. These solutions ultimately resulted in travel times being reduced in the cities.

Overall, by using innovative sources of data to collect mobility data could have positive results in cities of developing countries. The data provides valuable information on where intervention is required. Creative solutions still need to be made, but every city is unique and will oblige a unique solution. However, in the cases in this research, the information from analysing innovative sources has provided the fundamentals to implement successful interventions, where travel times have been reduced and ease of commuting has been increased.

7. Conclusion

To conclude this research, an attempt is made to answer the central research question using the findings that this research revealed. The central research question was formulated as:

How can innovative sources of data from collaborations between local governments and private organisations be used in urban planning/ policy decisions to improve mobility in cities in developing countries?

To adequately fulfil the answering of this central research question, a set of sub-question were formulated. These research questions have been answered in the previous chapter of this research with the findings. Those findings are summarised to provide a full answer to the central research question.

It was established that various techniques exist to collect data and analyse mobility systems. This researched managed to distinctly differentiate between traditional sources of data and innovative sources of data. Traditional sources included traffic sensors, as traffic management equipment that could independently retrieve data about traffic situations. There were also surveys as a traditional source of collecting data, these sources could be filled out by inhabitants or users of services to determine the quality of mobility systems. Both could be used to analyse mobility patterns, but also had their weaknesses, such as that they were fixed to a location or a population, from where the data was collected. They were also both expensive to deploy, a factor that made them unattractive or unattainable options for cities of developing countries.

Innovative sources of data mainly existed of data that was collected through mobile phone data of inhabitants. Data such as GPS locations and call data records. This type of data provided real-time information about traffic flows in a city, at relatively low costs. It could collect data about all modes of transportation, in every location of the city. Such data could be made accessible to the public in order to facilitate their commutes.

To gather mobility data through innovative sources, collaborations between local governments and private organisations could be arranged. Local governments don't always have the resources or expertise to capture and exploit the vast available mobility data that is circulating through innovative sources. These qualities can be found through the form of private organisations, such organisations could be telecommunication providers or transportation operators, but are not limited to these options. In cooperation, data from innovative sources could be collected to be analysed by local authorities or other stakeholders. This analysis could provide urban planners with information on where and how to implement interventions.

The data and analysis from innovative sources of data allow for several new solutions to be implemented. Of major importance to cities in developing countries is data that provides information about informal modes of transportation, such data could be retrieved from mobile phones of commuters. These informal modes are widely used, especially by poorer communities and can cause congestion due to their unregulated nature. By having knowledge about these informal modes, local authorities could improve their service or provide alternatives. In the case studies analysed in this research, there were several impacts of using innovative sources of data. In many cases, travel times could be reduced, also plans were made to reduce congestion in the city.

To ensure the success and attainability of using innovative sources of data to collect mobility data, several opportunities and challenges have come forward. Cities have to be able to provide its inhabitants with the opportunity to use mobile phones, such as by having access to the required networks. Another factor is that objectives have to be well-defined and understood between the different stakeholders involved. Furthermore, laws and regulations that allow for a smooth and reliable collection of data is of importance, if this is not present the possibilities are restricted.

Ultimately, to answer the central question of this research. Traditional sources of collecting mobility data may pose to be inefficient and unreliable for cities in developing countries. Alternatively, innovative sources of data could provide the information that urban planners are missing to optimise and improve mobility situations. Innovative sources of data could provide real-time data to identify where an intervention is needed. This type of data is abundant in most large cities of developing countries. However, local governments may not be able to attain such data on their own. By collaborating with private organisations such data could be generating and be made ready for analysis. As a result of having reliable information about all modes of transportation in a city, urban planners can implement effective solutions to improve mobility.

This conclusion concurs with the hypothesis and conceptual model that were formulated prior to this research. By increasing collaborations between local governments and private organisations, a flow of reliable data is generated. The data can subsequently be used to implement solutions that are effective in improving the quality of mobility in cities of developing countries.

8. Reflection

8.1. Limitations of research

This research has been able to answer the central research question with the resources that were available. However, this research also has several limitations.
Due to it being a research that crosses international boundaries, it has had its restrictions. Unfortunately, no primary data has been able to be manually recorded. This type of data could have served as a triangulation method to confirm what was found in the literature. Travelling to the areas that this research focuses on would have required a relatively high financial investment from a bachelor's student. It also does not fit in the time frame of this research, as travelling would have been too time consuming. Also, several equipment to measure traffic flows such as travel flows, and travel times would not have been available to use.
A lot of information has been found from various sources. It was conversely limited at times because this research focuses on different cases with unique situations. This made it difficult to collect the information about the same variables at times. This came at the cost of evaluating the specific impacts of each case in comparison to the other cases. Also, often there was limited information to be found on how a situation was before an implementation and how it was after. Certain case studies that were intriguing to research did not have sufficient information available to adequately describe. By having different types of information available for the different cases, reduces the reliability of this research. However, information that was found in the literature was mainly collected by professionals, that were equipped with adequate equipment to collect it. Therefore, providing this research with information that could otherwise not have been collected. This may have increased the validity of the research.

8.2. Recommendations further research

Recommendations that come forth from this research are based on the limitations of this research. It proposes a long-term study of such implementations by observing and measuring in the areas of interest. It would require finding cases where projects of collecting innovative data are yet to be started. By travelling to these areas and measure how a situation is initially. Then returning to the area to once again measure how the situation is after a project has been completed. The research should go in-depth about one case instead of several cases such as in this research. By conducting such a research, evidence can be collected about how much impact these projects have in reality.
A source of information that may prove to be valuable for future research is in the form of interviews. By interviewing key stakeholders that are involved in cases like the ones in this research, opinions and inside information may be retrieved on how the impacts of the projects are experienced.

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