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The use of digitalization and Internet of Things to help alleviate Traffic congestion in Addis Ababa, Ethiopia

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The use of digitalization and Internet of Things to help alleviate Traffic congestion in Addis Ababa, Ethiopia

by

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Abstract

Addis Ababa, the capital city of Ethiopia, has a population of just over 5 million people in 2021. This is 4.4% more than the population in 2020, and 8.8% more than the population in 2019 (Addis Ababa, Ethiopia Metro Area population 1950-2021). With rapid urbanization and economic growth Addis Ababa's transportation infrastructure is unable to meet the demands of the population. As a result, the city is facing high rates of traffic congestion. Based on the research conducted by Wondwossen Taddesse for his paper on 'Assessing & quantifying the level of traffic congestion at major intersections, the average traffic congestion intensity in Addis Ababa expressed in Veh-min or person-min is very high and the result shows on average about '*18,500 Vehicle-min* or *38 vehicle-days* and *169,000 Per-min* or *352-person-day* are wasted at each intersection legs or congestion spot per day' (Taddesse). Traffic congestion is a major global urban issue. It is be caused by several multilayered factors including but is not limited to the following: road lanes, parking area, road signals, effective traffic management, lack of manpower, lack of resources, and lack of public transportation.

The intent of this paper is to understand the major contributors of traffic congestion and identify the factors can be effectively resolved with the help of internet of things (IoT) along with the integrations of digitalized systems in Addis Ababa, Ethiopia. With the help of the World Bank, World Resources Institute (WRI), United Nations and other private organizations and institutes we conducted a comprehensive study and propose a two-part solution to the traffic congestion in Addis Ababa Ethiopia; improvement of the road infrastructure and the development of a smarter traffic management system.

Key Words: Internet of Things (IoT), Smart Traffic Management, Traffic analysis, Intelligent traffic management system, digitalization, smart city infrastructure, Traffic congestion

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Chapter 1 – Introduction

1.1 Introduction

Traffic congestion is a global phenomenon in urban areas. A few of the cities around the world have been able to reduce the issue and almost none have completely resolved it (Koźlak, and Wach, 2018). In developed countries traffic congestion is typically due to the concentration of socio-economic activities in a central location. This creates a high demand for transportation towards a concentrated location at specific times of the day. The common trend is long commute distances due to high housing rates closer to places of work. The further the distance traveled often also means limited mobility means. This creates high traffic during certain times of the day leaving the street empty and almost vehicle free during work hours. In developing countries, traffic congestion is caused by similar factors in addition to lack of physical road infrastructure, poor driving disciple, poor traffic policy enforcements, lack of alternative transportation, and more.

In fast developing cities like Addis Ababa, the capital city of Ethiopia, traffic congestion has become a consistent issue throughout the entire day due to multiple factors. These issues include inadequate physical road structure, lack of safe separation for pedestrians, animals, 3-wheeler motorized vehicle and larger vehicles. Additionally, traffic congestion is also increased due to traffic accidents with slow response and processing times, lack of regulation on vehicle capacity, poor driving disciple which can be a consequence of inadequate training, and lack of traffic violation enforcements. Like most urban areas, heavy traffic congestion in Addis Ababa has major economic, social, and environmental impact. It negatively impacts the quality of life of its citizens as they find themselves idle in traffic for hours. The consistent congestion throughout the day makes it very difficult for the transportation of goods and services. Due to the lack of technological advancement, Addis is still highly dependent on physical mobility for day-to-day transactions that have otherwise been digitalized in many other countries. A simple example can be banking transactions. With the consistent traffic congestion throughout the day the economic impact on businesses has increased significantly.

Traffic congestion is not unique to Addis Ababa. The rate at which road infrastructure and public transportation are developed rarely meets the rate at which urbanization is taking place. Even though traffic congestion is a common challenge amongst many cities the reasons as to why each city is facing traffic congestion may vary.

In 2017, Ethiopia's car to people ratio was 6 cars to 1,000 people making it one of the lowest rates of car ownerships in the world (Gorham et al, 2017). However, it boasts the highest accident and has terrible traffic congestion relative to the low number of registered vehicles. In 2018, more than 59% of the registered cars in the country were registered in the capital city ('Addis Ababa City Transport Strategy 2021-2030', 2021). Despite an increasing number of vehicles, the largest transportation mode share belongs to pedestrians, at 54%. Public transportation and private cars account for 34% and 15% respectively (Moges, 2020). Despite the low use of motorized vehicles in the city, Addis Ababa's Road infrastructure has been designed with motorized vehicles at the heart of the focus. Therefore, the roads do not meet the need of majority share. The lack of infrastructure for NMT creates multi-layers problems. It becomes a big contributor to traffic congestion as pedestrians, street vendors, animals, and cyclists are sharing car lanes with motorized vehicles. This results in traffic slowdown, unsafe driving conditions and ultimately increased traffic congestion.

1.2 Project goals

Following the economic and population growth Addis Ababa, Ethiopia is experiencing heavy traffic congestions despite the improving road networks and limited number of vehicle owners. The goal of this paper is to understand the major contributing factors to traffic congestion in this fast-developing city and propose solutions to alleviate congestion by integrating digitalized systems, internet of things, and by making use of todays advanced technological opportunities.

1.3 Aims and Objectives

This report stems from my experience of driving through the city of Addis Ababa. The level of congestion in the city throughout the day has reached a level of high hindrance. The report aims to identify issues that are contributing to increased traffic congestion levels. Following the identification of factors contributing to traffic congestion the objective of the report is to recommend ways to help reduce traffic congestions while taking into consideration the future of mobility.

The method in which this report aims to find solutions was inspired by a book called Atomic Habits by James Clear. In his book, James Clear writes about peoples' habits, decision making, self-improvement, and goal setting. James tells his readers about the impact of 100 small changes to reach one goal through the example of the British Cycling team in 2003. This reports the aim to do just that; to find as many small improvements as possible, when accumulated the results will be faster and better in comparison to large and costly projects.

1.4 Research Methodology

The basis of understanding the issues related to congestion in Addis Ababa along with cities alike came from a review of published works and publications from websites, universities, associations, and publications of private entities working in the sector.

Additional information was collected through brainstorming conversations with subject matter experts from the World Resources Institute (WRI) and The Urban Center. Talking with professionals who are currently involved in the transportation sectors was eye opening and provided a perspective from the implementation of current projects.

Furthermore, quantitative data, of commute times, was extracted from google maps using a web-based platform called Outscraper; a website used to extract different types of public information from google maps. 5 different data sets of commute times over 4 mouths were extracted from the 5 different routes. Each route selected was a possible commuter experience

from a popular residential area to one of the major market areas in the city. Once these data sets were downloaded an interactive data visualization software, tableau, was used to analyze the date.

Lastly an expert elicitation was performed with 2 professionals in the field to understand the feasibility of smart solutions for Addis Ababa. Congestion is a multilayers problem within the complex system of the transportation sector. Finding theoretical solutions to real problems is of no value if the feasibility of the solutions is not addressed. Therefore, the expert elicitation was deemed to be important for this report to help understand the probability of smart solutions for traffic congestions issues in Addis Ababa given the experts past and current expertise in transportation related projects.

1.5 Limitations of the study

It was difficult to find literature reviews on digitalization of urban transportation based in Addis Ababa. The topic might have been too contemporary given that current development level of the city. The lack of research and related articles suggests that smart solutions or digitization of the transportation infrastructure has not been deeply considered for the city at a large scale, and if there has been it has not been made public. Based on discussions with expert matters it has become clear that some government entities do not want to have a digital platform as that would require more transparency and less government control on the country's statistics.

Chapter 2 – Literature review

The research gathered on traffic congestion in Ethiopia and in other global cities were sourced from published articles, thesis studies, international development consultancy websites, articles, and interviews. Due to the lack of literature directly pertaining to smart transportation for Addis Ababa, majority of the literature topics were related to congestion levels of Ethiopia, road safety, and alternative means of transportations to help curb the public transportation shortage. Due to

the limited literature available, the review included publications on congestion, and technology-based solutions of other cities as case studies. Additionally, the success of digitalization of transportation was also assessed during the literature review to solidify the suggestion to use technology as a means of solving congestion levels in a developing country.

The literature review is broken down into sections; understanding traffic congestion levels in Addis Ababa, the factors contributing to traffic congestion, congestion detection and solution-based articles, what should be considered when looking forward, and the success of integrating technology into the transportation infrastructure.

Background and traffic congestion levels of Addis Ababa

The average urbanization rate for Ethiopia over the last few years has been 4.89% (The World Bank, 2021). It is one of the least developed counties in the sub-Saharan regions with one of the lowest rates of car ownership in the world and yet experiences heavy traffic congestions levels. Based on the research conducted by Wondwossen Taddesse for his paper on 'assessing & quantifying the level of traffic congestion at major intersections in Addis Ababa, the average traffic congestion intensity in Addis Ababa expressed in Veh-min or person-min is very high and the result shows on average about *18,500 Vehicle-min* or *38 vehicle-days* and *169,000 Per-min* or *352-person-day* are wasted at the studied intersection legs or congestion spot per day' (Taddesse, 2011). Traffic congestion has been a major urban issue globally. It can be caused by several multilayered factors including but is not limited to the following: road lanes, parking area, road signals, effective traffic management, lack of manpower, lack of resources, and lack of public transportation.

Given that Ethiopia is a developing country the transportation infrastructure is underdeveloped and therefore cannot meet the travel and safety needs of its residents. Therefore, the focus of most research regarding transportation in Ethiopia has thus far has been on improving safety and dependability. These research articles mainly revolve around road safety, accident rates, and response times to illustrate the unsafety of the roads (Samson, 2006). The reasons for unsafe road conditions also contribute to slower travel times. For Instance, vehicle accidents and emergency service response times, and lack of pedestrian walkways all contribute to increased

traffic congestion. Moreover, the solution or recommendation for these literatures are open ended and unfocused which makes implementation and funding difficult. The studies address the need for more technology however, the reports do not specify what type of technology, implementation methods, nor how technology can aid in creating safer conditions.

In response to the high levels of traffic accidents in Addis Ababa the World Bank has an ongoing impact evaluation and improvement projects. It aims to increase road safety and reduce traffic congestion related issues with the primary focus still being on safety. Through their research they have found that the issues contributing to traffic congestion come from 'inadequate planning for, poor management of, and weak compliance with land use and transport measures. Additionally, the integration of land use and transportation infrastructure is insufficient, manpower, and resources to plan for them are limited' (Lloyd, 2019). To solve for this issue, the World Bank and the Government of Ethiopia are currently working on upgrading intersections within the five main corridors in the city. These upgrades to the intersections aim to improve road safety for vehicles and pedestrians alike. In addition to road safety the initiative will also introduce smart radios to a study group of 500 police officers. The aim with these smart radios is to improve and collect data or policy enforcement as the city is known for its poor re-reinforcement of traffic violations. Both these initiatives were to be completed by 2020 and start gathering information via observation and video capturing (World Bank Group, 2021). The success of the completed intersections was done manually by Jiregna Hirpa, the deputy director of Addis Ababa Road Traffic Management Agency at the time. His presentation shows us that the completed intersection improvements have been successful in increasing road safety with a 50 percent reduction in fatal accidents in specific intersections (Hirpa, 2017). The integration of technology into the infrastructure would have allowed for data collection and analysis for the future.

Congestion detection and solution-based research

Transportation networks in cities are associated with the history of the city developments. Meaning that the transportation network that was built in previous eras will no longer serve the current transportation needs of the city. However, it very difficult and nearly impossible to to

modernize and make the old networks fit today's urbanization. Therefore, the only solution for existing networks that cannot be modernized is through efficient management (Korableva et al., 2021). A lot of cities around the world have attempted to solve from traffic congestions with new transportations network when possible while maintain the old when unable to. Most of the solutions that have proven to be effective can be categorized into six; better integrated urban planning, promotion and integration of public transportation, intelligent transportation system, strict lane management, supply and demand, and effective traffic policies (Kumar & Singh, 2017).

More specifically, the publication 'Enhancing Intelligence In Traffic Management Systems To Aid In Vehicle Traffic Congestion Problems In Smart Cities article' by Rocha Filho, Geraldo P et al tried to provide a more efficient way to reduce traffic by detecting congestion levels and distributing them to the necessary drivers and personals that find the information relevant. People can request information based on their commute routes by subscribing to certain route information channels. That information can then be disseminated even further again through the receive and request platform to other people not on the subscription. This solution for traffic congestion levels depends heavily on information distribution. The authors found this solution to be the most successful form of alleviating congestions levels. Another solution that has proven to be successful in multiple cities, globally, is the development of a traffic command center. Cities like Berlin and Chelyabinsk have connected numerous devices such as video sensors and cameras on a single network to their respective traffic command center. These devices have allowed them to collect data and information that has helped make operational decisions to alleviate traffic conditions (Korableva et al., 2021).

The advantage of introducing new solutions to the transportation system of Addis Ababa is that the electronic infrastructure can be installed at the same time as the physical infrastructure is being built. This can have great cost saving potential versus having to retrofit already existing structures with the electronic infrastructure. The lack or limited amount of technology-based infrastructure allows the government to consider more options as they are not limited to upgrading already existing systems or spending larger funds to change the old technology for a new one. The transportation sector has the opportunity to study and assess from other cities what has been successful and implement something that can effectively adapt and be integrated

to the local infrastructure. (Pojani, and Stead, 2015). For instance, the success of Moscow city evolving from the most congested city in 2010 down to the 13th congested city in 2016. In the McKinsey conducted interview with Maksim Liksutov, Moscow's Deputy Mayor for Transport, we can start to understand the type of transformations that helped reduce the congestion levels in Moscow. Like Addis Ababa, Moscow started reforming their transport system later than most world capitals and therefore they took this opportunity to learn from other cities such as London, Tokyo, Beijing and Singapore. Every city has its own unique characteristic and a solution for one cannot be the solution for another. However, lessons can be learnt, and adaptations can be made to a solution for different cities. Moscow found utilized systems like 'electronic ticketing systems, city bicycle systems, bus lanes, regulated taxi industry,' (Liksutov, 2018) all for one payment systems, and more. What all these systems have in common is the digitalization of the systems. This helped in the collection of data as well providing a seamless transfer from one system to another in terms of usership and for coordination between different entities within the overall transportation infrastructure.

Command centers, or Transport management Center Operations (TMC), have been built in many cities to help improve management of transportation infrastructure. They have 'been at the forefront of leveraging technology to manage transportation' (Mizuta et al.). The centers show how information and technology can be harnessed to improve management and operations. However, there are challenges as well that need to be taken into consideration. The constant evolution and new emerging technologies require large budgets and constant maintenance and updates. The centers much keep up to date as other agencies and technologies around them will evolve. Updating software and hardware are also crucial in defending against cyber threats. On the opposing side, new trends like wireless communication and social media have shown great opportunities for command centers and TMCs. These outside party trends have created a large collection of data and creating the opportunity for a two-way data and communication stream. Transportation networks can take advantage of third-party collected data through increased variety and coverage, and real time information. These third-party sources can help boost performance, increase inter-agency coordination, and collaborations (Mizuta et al., 2013).

Through research it was not clear if the highly anticipated traffic control center for Addis Ababa has been completed. The project was announced in 2020 with an estimated construction time of 18 months. The 'control center aims to make traffic safer and better regulated, reduce congestion and CO_2 emissions' (Gust-Kazakos, 2020).

Looking forward

It is essential to anticipate and plan for potential issues that could arise in the future when exploring solutions for traffic congestion. Some cities have been successful in finding solutions for their traffic congestions and some of them have not been as successful. Both of these have valuable takeaways. The solution to our problems cannot be a temporary solution but one that can be integrated into the future as well. Its analysis mobility of 66 different countries to see where the overall world is in terms of mobility and what the future holds (Lerner and Arthur, 2012). This index allows us to understand where Addis Ababa is relative to other cities so that we can learn from those that are achieving lower congestion levels and what issues they are currently facing to help anticipate and avoid similar miscalculations.

Institute for Transportation and Development Policy (ITDP) with support from UN Environment and UN Habitat have produced a non-motorized vehicle strategy to be completed by 2029. The article states that more than 50% of the mobility is walking and/or cycling. This article also provides guidelines on resource management and partnerships between different public and private entities. The guidelines highlight important points but do not dive deep into the details of how these will be carried out and managed. The main priority of the government, according to research, is to provide better transportation opportunities for the low-income families and encourage women using public transportation by making the system safer. Solutions to help lower traffic congestion should consider strategy plans that have been previously deployed (Moges, 2020).

Digitalization within the transportation sector

When planning forward and looking for long term solutions city leaders need to consider that not all cities develop in the same way and that every city has its own challenges. However, the things to be considered for all city leaders is the same; they need to keep consider the type of

technologies that will best suite the city, the business-model innovations, policies, and consumer preferences. The last factor is where digitizing comes in handy. The new technology can provide the data and analytics needed to help understand customer usage and movement patterns, to make decisions, in real time (Bouton et al., 2016).

One of the main questions that comes up when attempting to resolve congestion issues with digitalization is how digitization impacts transportation systems. Congestion is not unique to Ethiopia; it is an issue faced by almost all urban areas globally. Most of which are experiencing congestion due to similar reasons. Some cities have looked towards digitalization in hopes of a solution. 'In 2012, the McKinsey and Global Institute concluded that, globally, $400 billion a year could be saved by making more of existing infrastructure through improved demand management and maintenance' (Neumann, 2015). This will be done using dig data; 'the collection and strategic use of information' (Neumann, 2015). Success stories of the integration of data into the transportation sector goes beyond the examples of Israel's fast lane highway, Brazil's aviation traffic, and railway-infrastructure mentioned in this article. However, the incorporation of information and infrastructure has been slow. Economic viability is not a proven reason for the slow linkage of the two. It is found that the payback from investing in this integration is much better than investing in equipment that will boost capacity. The main reasons that integration of big data to the transportation infrastructure has been slow is primarily for three main reasons; lack of transparency between stakeholders, sharing of costs versus benefits, and that not all stakeholders have the same goal. this reason has slowed down the progress of transportation in many cities across the globe and is very relevant to Ethiopia as well. When thinking of ways to solve traffic congestion these reasons must be considered.

The use of technological advancements can be as small as providing applications and services through smart phones. For example, Mobility as a Service (MaaS) can potentially help in the reduction of private car ownership by shifting transportation modes from private cars to public transportations. With less cars on the road congestion times will reduce (Schroten et al., 2020) MaaS can also increase efficiency within the transport sector as it helps connect all the players in the MaaS community. It provides directions using multiple modes of transportation.

The main ideas and take away point from the research conducted for this paper are as follows below:

- Addis Ababa has very low car ownership rate, however, the residents experience high levels of traffic congestion.
- Most published works regarding the transportation sector in Ethiopia revolves around road safety and reliability therefore technology-based transportation systems have not been fully developed.
- The research shows that traffic congested in Addis Ababa is caused by inadequate planning, poor management, weak compliance with land use and transportation measures.
- Generally, the solution for traffic congestion lay under the following categories: improved public transportation, intelligent transportation system, strict lane use, supply and demand, effective traffic policies.
- Developing a traffic command center to connect all transportation systems has proven to be an effective method of reducing traffic congestion.
- Technology based solutions have also proven to be effective ways of alleviating traffic congestion, this includes the dissemination of information to drivers in real time.

Chapter 3 - Project Description

The purpose of this project is to understand the level of traffic congestion in Addis Ababa, what causes this congestion levels and to understand if the integration of technology, in other world smart mobility, help alleviate the traffic congestion.

Chapter 4 - Data Analysis

4.1 data set of traffic congestion in Addis Ababa

To understand the level of traffic congestion in the city, four different routes were plotted on a map of Addis Ababa. This map shown below in Figure 1 was created by a team of urban planners, at The Urban Center, as part of their research on transportation in Addis Ababa. The map, as seen below from appendix 1, highlights major market centers, major clusters of residential areas as well as other important city services.

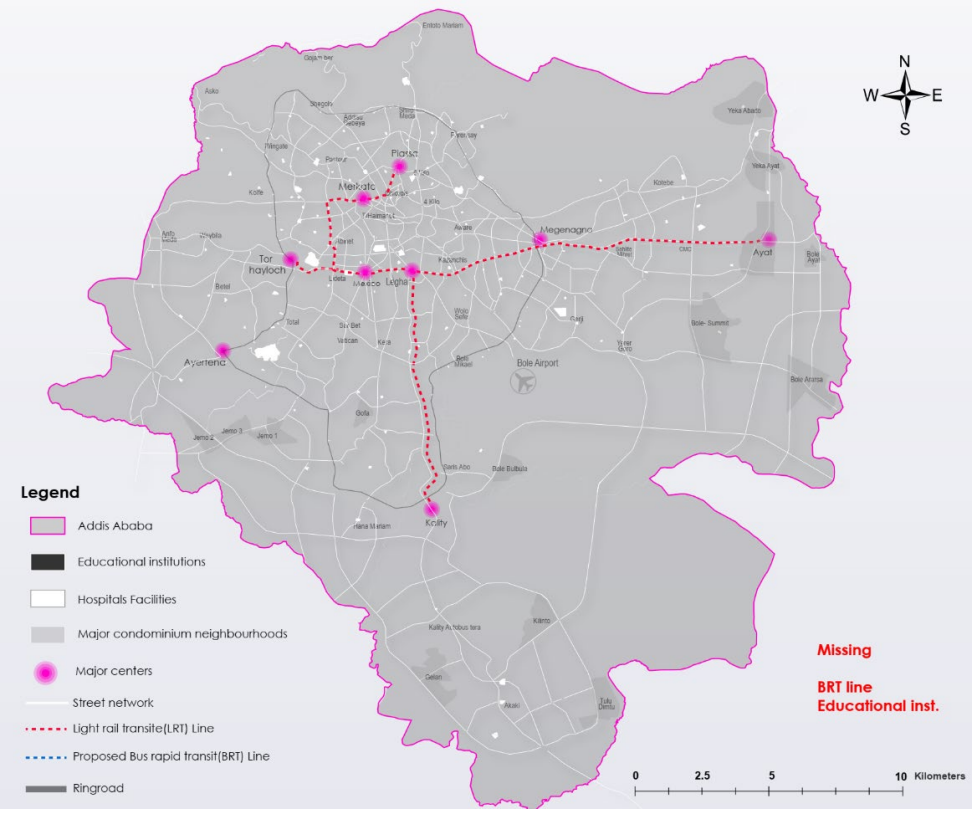


Figure 1. Map of Addis Ababa showing major city services (The Urban Center, 2020)

The four plotted routes were intentionally set to show traffic congestion levels for people that commute long distances. Short commuter routes were not taken into consideration for this research. Each route was then mapped into a website called Outscraper which helped create and download data sets from using google maps. The parameters for each data set were set to

hourly intervals per day over the course of four months, January 2022 through to April 2022. The graphs below were generated using Tableau to help visualize commute times over the course of a day, over the course of four months.

4.2 Data analysis of the Dataset on travel time

The following graphs show the travel time trends from January 2022 till April of 2022. Each graph represents one of the selected routes mentioned in section 4.1.

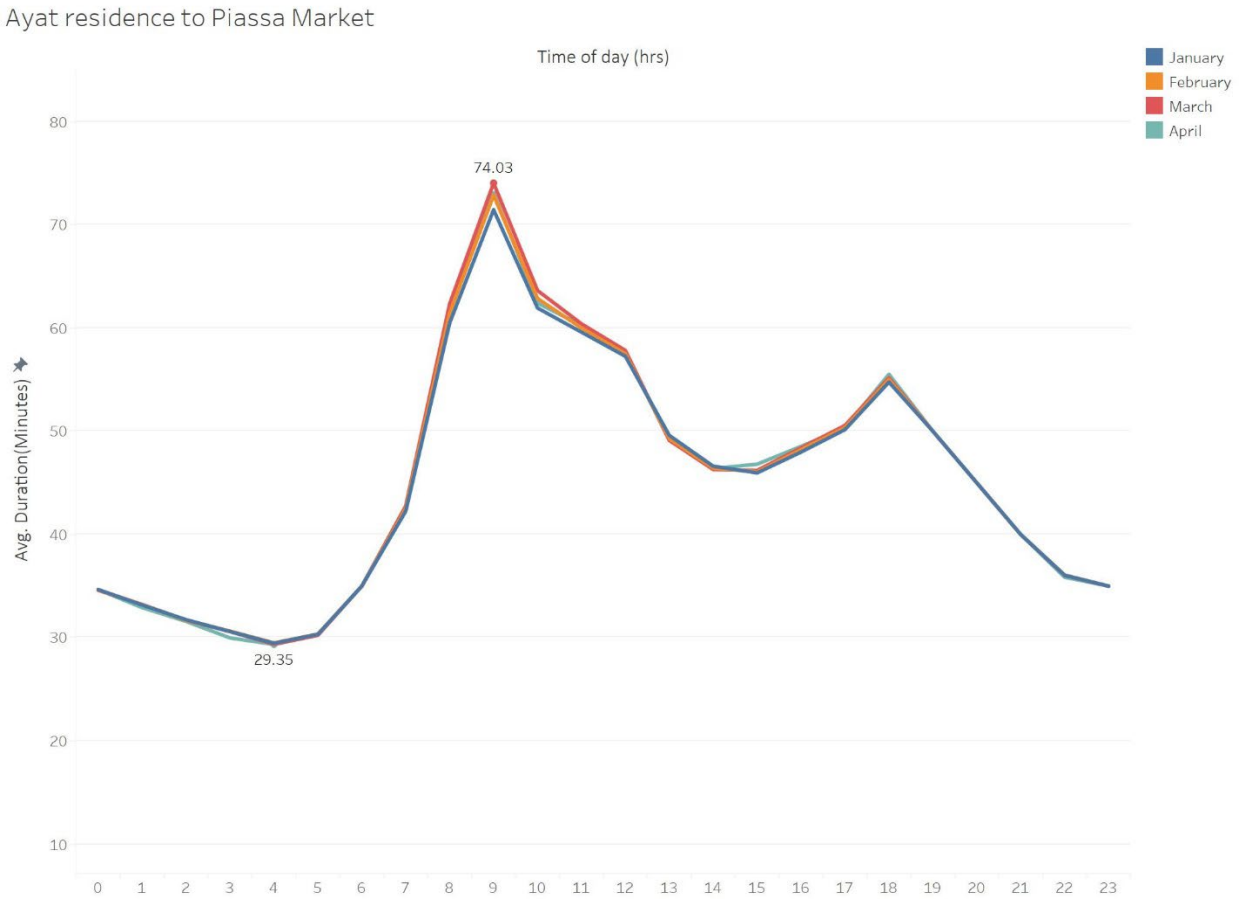


Figure 2: Travel time from Ayat residential area to Piassa center

Figure 2 shows that the shortest commute typically occurs at 4am taking an average time of 30 minutes to commute a 16km route from Ayat to Piassa. At peak hours the same route takes an

average of 74 minutes which is 146 percent increase in commute time between the hours of 5am to 9am followed by a sharp decline for the following hour. This spike in travel time is as expected given the morning rush hour to work and school. However, the travel time does not go back to minimal travel time outside of the typical rush hour time. There are other causes of traffic delay that is not related to the concentration of vehicle towards a common direction. Traffic delays remain double the minimal average time throughout majority of the day and night.

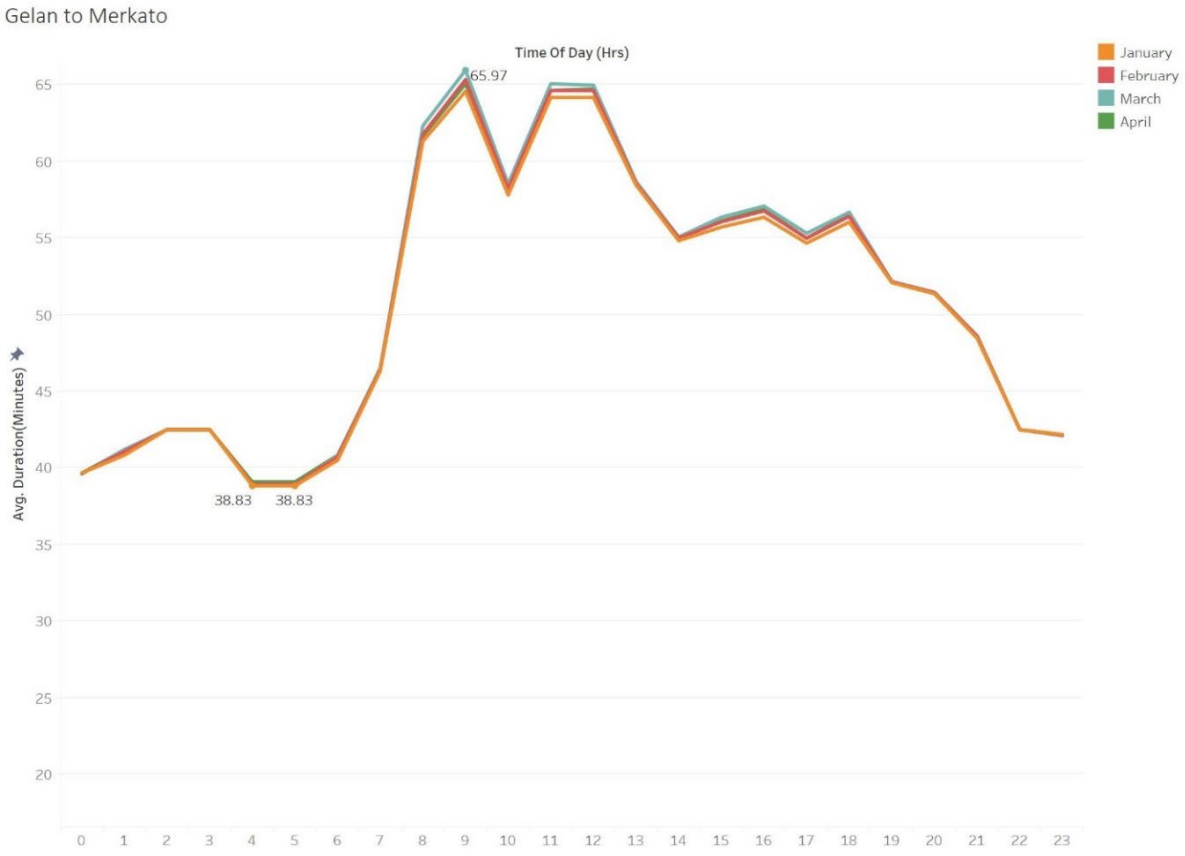


Figure 3: Travel time from Gelan area to Merkato commercial center

Merkato, located in the northwestern part of the city is 'one of the largest open-air markets in Africa' (Britannica, 2021). During work hours the streets of Merkato are buzzing with people. One of the routes used to assess traffic congestion in the city includes a 32km commute from a southern residential area, Gelan, to Merkato. The minimum average commute time takes 39 minutes, whereas the maximum commute time is 66 minutes. After the morning rush to work there is a small decline in commuting time. Similar to figure 2, this route also includes a 20-

minute travel delay throughout the day with commute times showing less than 50 minutes after 9pm.

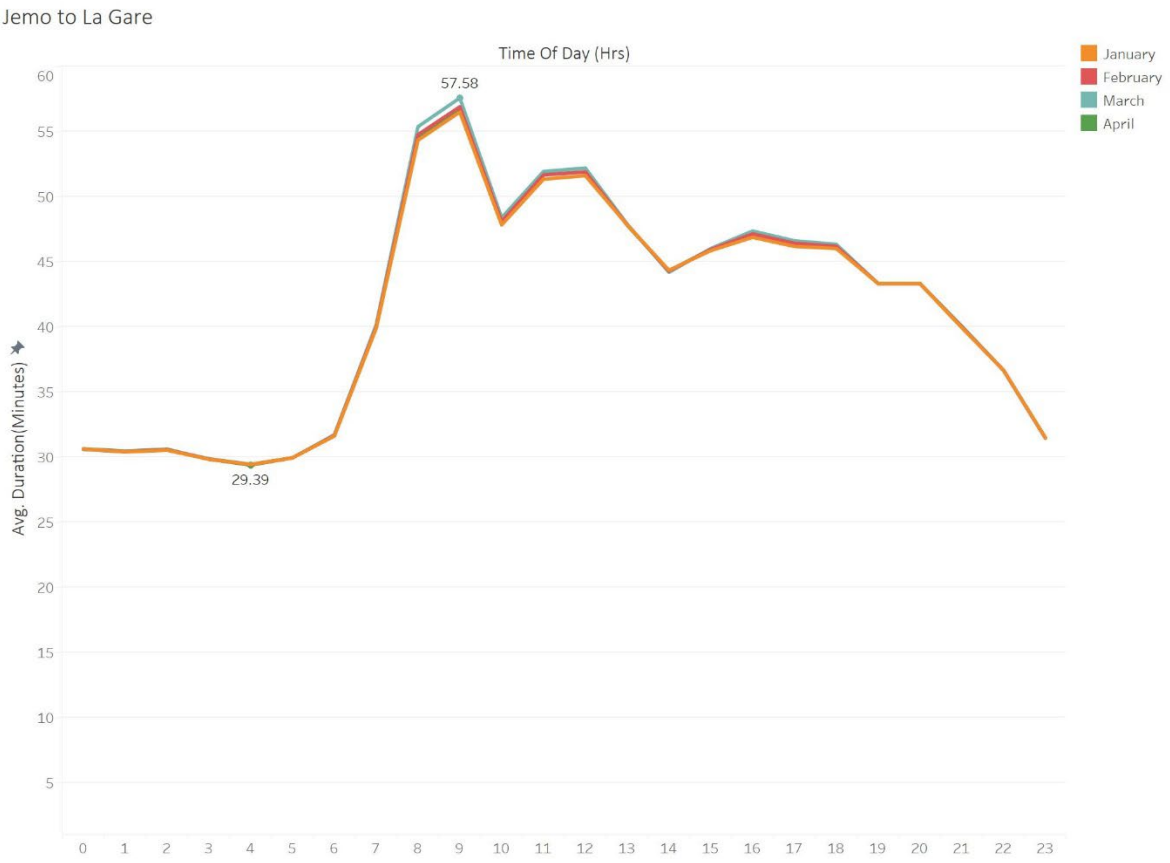


Figure 4: Travel time on the route from Jemo to La Gare

Jemo is a relatively new suburban area located far west of the city. It is comprised of gated community housing for high income families as well as large scale affordable apartments, known as condominiums in Ethiopia. Figure 4 above shows the average commute time between Jemo residence to La Gare center per hour over a duration of four months. La Gare is known to be a busy and dense area with a lot of commercial activity. La Gare which translates to The Station in French was once the terminal station for the Addis to Djibouti railway (Kozicki, 2018). In this commute, from Jemo to La Gare, the traffic congestion is at its peak during the morning rush hours and shows a decline towards midday. There is an increase in traffic delays starting at the 2pm mark and holds a traffic delay of more than 15 minutes till 6pm. The traffic congestion level

on this route seems to be minimal in comparison to the routes in the graphs shown in figure 1 and 2. However, it still holds irregular traits throughout the day suggesting that other factors are causing traffic congestion outside of the anticipated rush hour times.

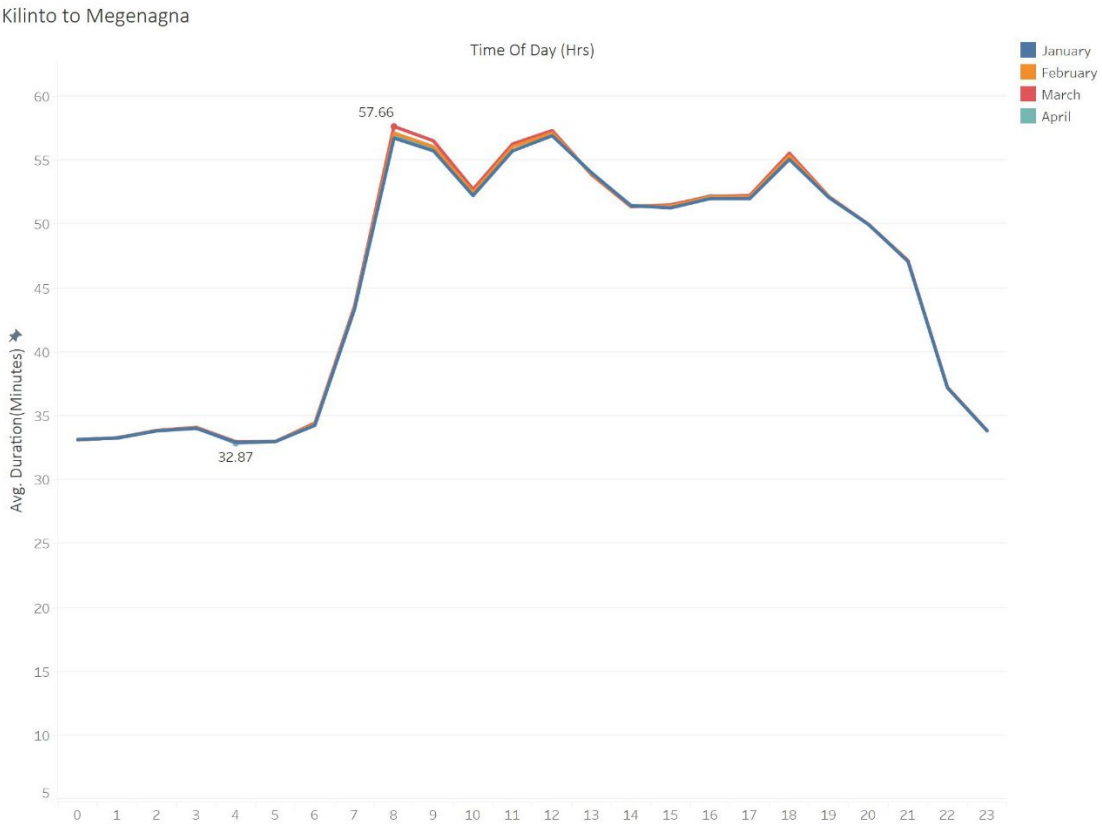


Figure 5: Travel time from Kilinto residential area to Megenagna commercial center

Kilinto is an area found south of the city. It is home to two industrial zones and a large brewery owned by Heineken. It also has large-scale affordable housing near the industrial zones to provide housing for workers in the park. However, not every member of the families residing in that area will work in the industrial parks. Some of them commute to the city, and it is most likely that they will commute to Megenagna. Megenagna in Amharic means meeting point or intersection. It is a place where the light rail, highways and many roads connect. It is also home to a large bus and paratransit terminal. Due to the large number of crowds going through the area it has developed into a commercial center with large buildings as well as informal street vendors selling fruits, clothes, shoes and more. Kilinto to Megenagna is a 23km commute with

travel times taking an average of minimum 33 minutes to 58 minutes. Most of the people residing in the Kilinto area rely heavily on public transportation to get to their destinations, which is another reason to travel to or through Megenagna center. The commute times during the morning rush hours are as anticipated. Yet again, commute times remain high throughout the day, staying well above an average commute time of 50 minutes until 8pm. Most public transportation stops service after 8pm which is the reason for the sharp decline in commute time after 8pm.

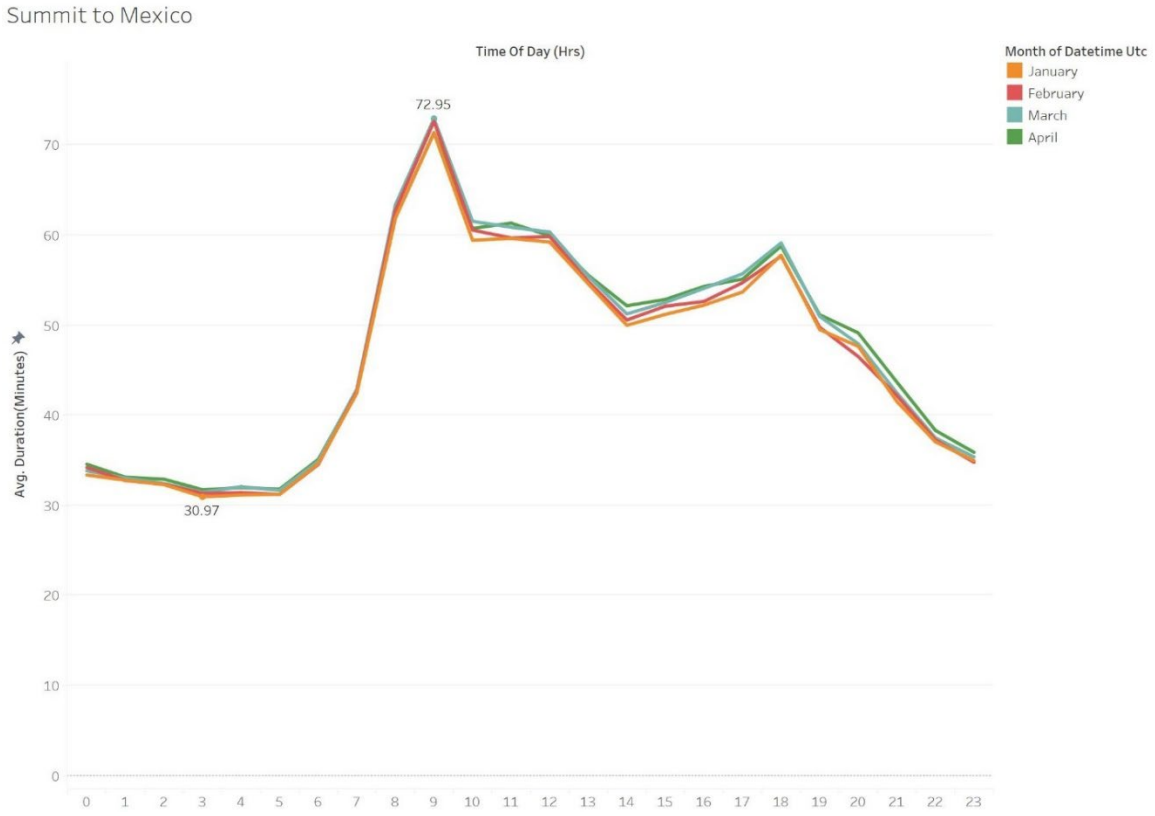


Figure 6: Travel time from Summit residential area to Mexico center

Summit is an up-and-coming residential area that has housing for all income levels. The area is known to have new construction housing with cheap rent attracting a lot of people to the area. Figure 6 shows the average commute time for a person working in one of the major centers identified in the map, Mexico. The commute distance from Summit area to the center of Mexico is 19km. It takes 31 minutes to travel that distance without traffic congestion. During the

morning rush hour, it can take up to 73 minutes on average. The traffic congestion is still prominent during the day as commute times remain above the 50 minutes on average till 7pm. In this graph we can see that there is a slight variation on the average commute time from January to April. the average commute time is increase slightly increase per month.

4.1.1 Findings

All the graphs shown in Figure 2 to 6 show that there is a minimum of 15-minute delay outside of the normal rush hours, the morning and evening. The traffic delay is a persisting issue rather than anomalies that occur randomly. Therefore, we can assume that there are other reasons as to why traffic congestion occurs on a regular basis. To find out what the traffic delays were caused by pictures were taken along the routes at points of congestion to show the reasons. Another common issue along many streets of Addis Ababa is the lack of physical infrastructure for non-motor modes of transport. The image below shows the lack of pedestrian friendly pavements on a major road in the city.

Figure 7: Image of pedestrian sharing motorized vehicle lane.

Pedestrian pavements can be found in certain areas of the city. In some areas these are used for the intended purpose, to provide safe and dedicated areas for pedestrian walking. However, in some areas these pedestrian walkways are occupied by street vendors, on a daily occurrence.

Figure 8: Image of Street vendor selling on pavements.

Figure 8 above, shows street vendors taking up almost the entire pedestrian walkway forcing the pedestrians to share the roads with motorized vehicles. The informal market. The informal market accounts for 33.5% of the total GDP, for Ethiopia (Fransen and Dijk, 2008) It also contributes to 26% of employment in Addis Ababa alone (Fransen and Dijk, 2008), and therefore remains and integral part of the economy. It is a norm in the city to share motorized vehicles lanes with bicycles, pedestrians, and sometimes animals. This slows down traffic causing delays throughout the day. Additionally, traffic congestion was due to several underlying factors such as the concentration of economic activity within the city center, increase in private owned vehicles,

less popularity of public transportation as population increases, lack of policy enforcements, and lack of parking facilities. The lack of designated parking along with free street parking has heightened the issue by creating narrower streets for moving cars and reduced vehicular speed. Below is an example of lack of policy enforcement that causes major traffic delays in the city.

Figure 9: Image of a public bus dropping off passengers illegally

In figure 9 above, we see a public bus on the inner lane of a highway dropping off its passengers instead of using the shoulder lane on the right, separated by a metal barrier. Parallelly, we can see a bus shelter on the shoulder lane in exact same location as the stop made by this bus. The lack of policy enforcement has allowed random stops on illegal lanes. In this instance, it causes

major traffic to slow down on a highway, other vehicles are prone to accidents, and it creates and unsafe crossing condition for the passengers.

Chapter 4.2 Expert Elicitations

4.2.1 Introduction

Improvements in the transportation infrastructure in Addis Ababa has been relatively slow. The delay in road work construction have been narrowed down to five major factors; 'financial difficulties, escalation of material price, ineffective planning and scheduling by contractors, delay in progress payments for completed works, lack of skilled professional in construction project management in contractor organization' (Miresssa, 2019). For better understanding of the likelihood of Addis Ababa's transportation governance in digitalizing the systems, expert elicitations were conducted with 4 experts. Table 1 below provides general information about the interviewees.

Expert	Education Background	Current position	Experience in field (in years)	Color designation
1	B.S Architecture and Urban Planning	Project manager at The Urban Center	20	Blue
2	M.S Environment, Development and Policy	Urban Mobility Project Manager for WRI Africa	5	Orange
3	B.S and M.S in Urban planning and design	GIS Research Analyst, WRI Africa	8	Grey
4	M.s Engineer	Transport Engineer and Lecturer at Addis Ababa University	9	Yellow

Table 1: Expert interviewee's background information

4.2.2 Elicitation

All the interviews started in an informal discussion about the topic. We discussed the current status of the transportation sector in Addis Ababa, the future plans, if digitalization is a part of

the future plans, and to what degree does the government want to digitalize the system. During the interview process we discussed the feasibility for a digitalized system in a developing country and the impact it would have. Especially, given the large population that may not know how to use these new systems and the possible failure due to the steep learning curves and the cultural resistance to change. Following the initial conversation each expert was asked a series of questions. The experts were asked for their perspective on the likelihood of digitalizing the transportation sector, given their professional knowledge. The experts were first asked for their upper and lower bonds, respectively. Subsequently, the experts were asked for their confidence percentile between 90% - 5% in no specific order. Additionally, each expert was also asked to explain the reasons behind their answers. Using the values fm the interview a cumulative distribution function graph was made, as shown below.

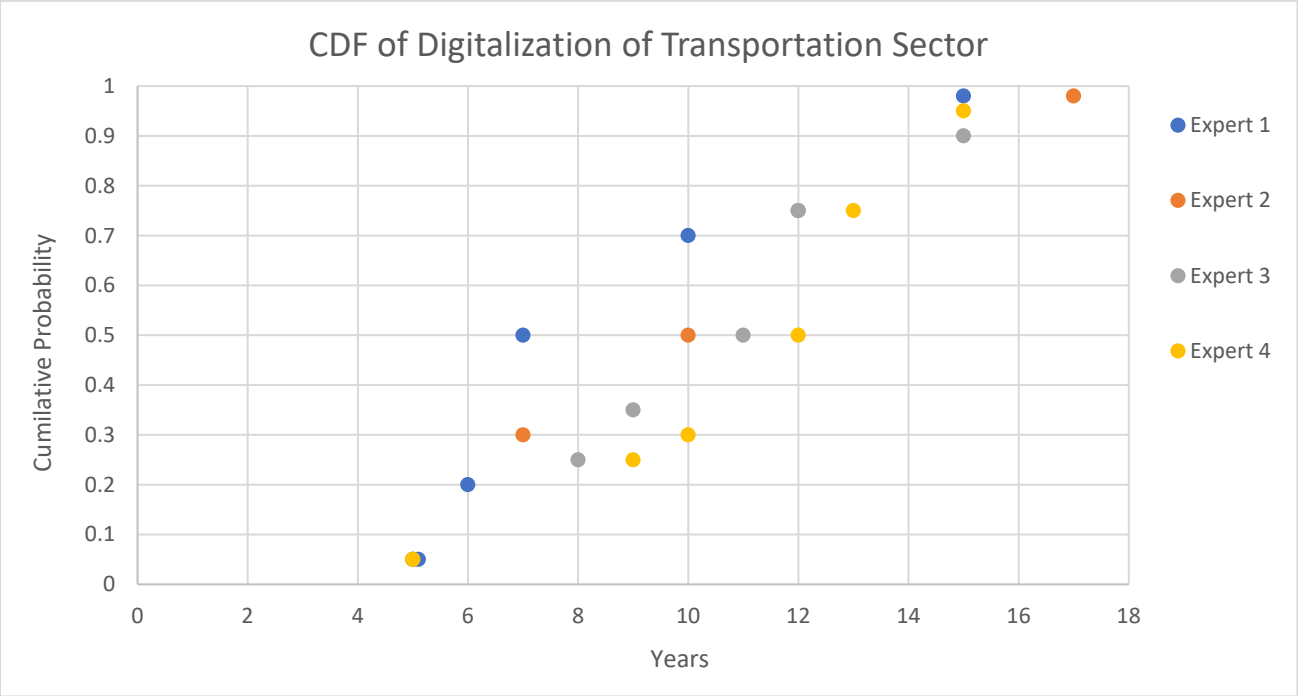


Figure 10: Cumulative distribution graph of digitalization potential of the transportation sector, Addis Ababa

4.2.3 Results

The graph, in figure 10, shows that the experts have similar confidence levels in regards to the digitalization of the transportation sector. All four experts predict that digitalization can happen within the 5-8 years range if all was to go according to plan. They remain optimistic because of the rate at which the country is growing. The development of the private sector will push the government to use technology to alleviate the transportation stress put on the city infrastructure. When asked how many years it would take for them to be 95 percent certain on the probability of digitalizing, three experts gave the same answer of 15 years. The experts all expressed their concerns regarding coordination between the different government entities, lack of clarity and accountability, and high corruption levels. All these are major contributing factors when dealing with the timelines of accomplishing the goal of digitalization. Expert 2, who works closely with government entities directly responsible for the transport sector explained that the government has all intention of digitalizing this sector within 5 years. The goal and the intention is there, however, the success of the intent relies heavily on coordination, clarity on the how, the clear delegation of tasks between entities, budget, and finally the ability of the people to adapt to the new technologies.

Chapter 5 - Solutions

The traffic congestion in Addis Ababa, Ethiopia is a complex multilayered issue that requires compounded strategies to solve for congestion using both short and long terms goals. It is important to understand the significance of making small improvements over time to achieve long-term solutions. These improvements can help make and shape citizen habits and policies over the years in order to create a shift in cultural and social norms. Based on the findings in section 4.2 this report provides a two-part solution for the traffic congestion in Addis Ababa; improving the physical infrastructure and transitioning to a smarter traffic management system.

5.1 The Physical infrastructure

The current physical road infrastructure is not adequate to support smooth vehicle movement in the city ('Addis Ababa Transport Strategy 2021-2023'). Not only are the physical conditions inadequate for motorized vehicle movement but they are also not equipped for safe and smooth non-motorized movement. The Addis Ababa City Road Authority has multiple active road improvement projects, all focused on improving motorized vehicular movement on main arterial roads. The government has not put much effort into the development of smaller secondary roads which are favorably used by drivers as alternative routes to avoid traffic congestion. The next section provides a detailed list of solutions that can help improve the physical transportation infrastructure in Addis Ababa.

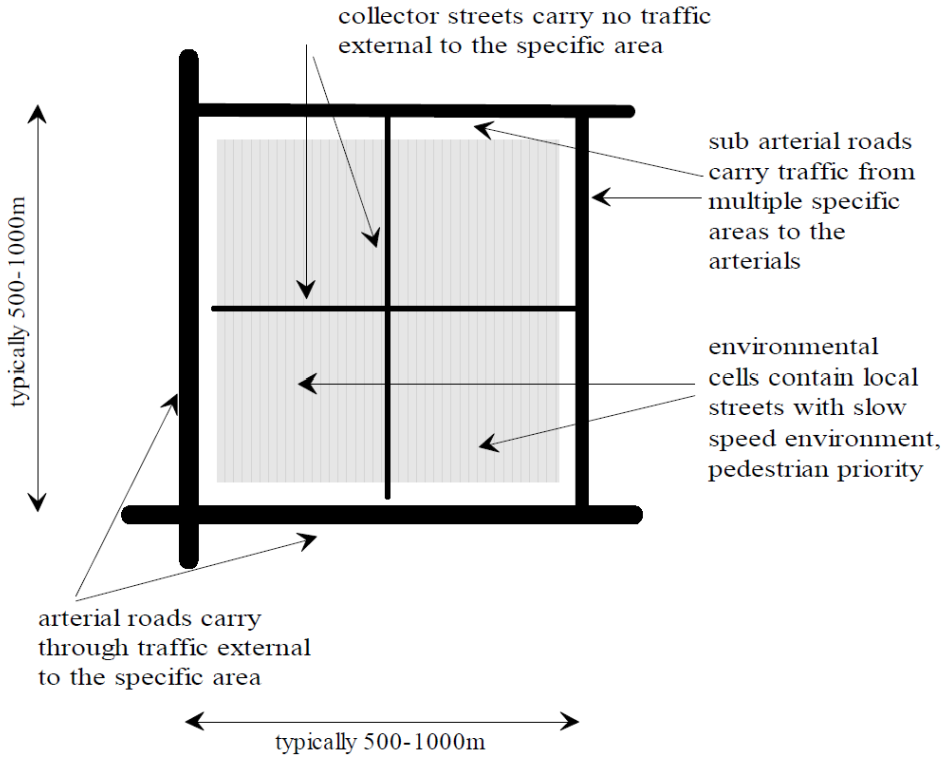


Figure 11: Area concept for a Four level hierarchy Planning and Management (Eppell, et al. 2001)

(1) The road network in the city should transition to using a hierarchy of road networks as an approach to alleviating traffic congestion. A hierarchy of road networks will give drivers the opportunity to use alternative routes to disperse heavy traffic flow. A Four Level Road Hierarchy design, as shown conceptually in Figure 11, is optimal for the road network development for Addis Ababa, Ethiopia. This type of road network includes arterial roads, sub arterial roads, collector roads and local streets. Arterial roads are designated for long distance through traffic movement that connect major urban developments in the city. Sub arterial roads connect local areas to arterial roads, and provide access to public transportation. Collector roads are pedestrian friendly, cyclist friendly and also provide access to public transportation and direct access to properties. These roads are dedicated for slower traffic and provide multiple routes to destinations which helps to disperse traffic. Local roads are small narrow roads dedicated for direct access to properties and that prioritize slow traffic, pedestrians and the greenery in the neighbourhoods.

The goals of the hierarchy is to optimize accessibility, connectivity, amenity and safety for all road users including motor vehicles, bicycles pedestrians, and public transport patrons' (Eppell et al., 2001). Optimizing accessibility and access to all modes of transportation can help reduce traffic congestion. The success of the four-level hierarchy design is also the management of land use and policy. It is essential to maintain and good job-housing balance within each neighbourhood. Each neighborhood or local area should be equipped with services such as hospitals and schools to reduce long distance travel to important amenities and services. These services and amenities can be controlled through the land use and zoning policies.

(2) Emergency only lanes should be incorporated for emergency use. One of the contributing factors to traffic congestion is the slow down caused by accidents and their slow response times. Having a shoulder or emergency only lane

incorporated into the motorized-vehicular lane design will allow space for vehicles to have a clear path for any emergencies. It will also allow for drivers to have space for emergency stops and car breaks downs, in lieu of leaving their car on the main roads causing blockage and a bottle neck scenario.

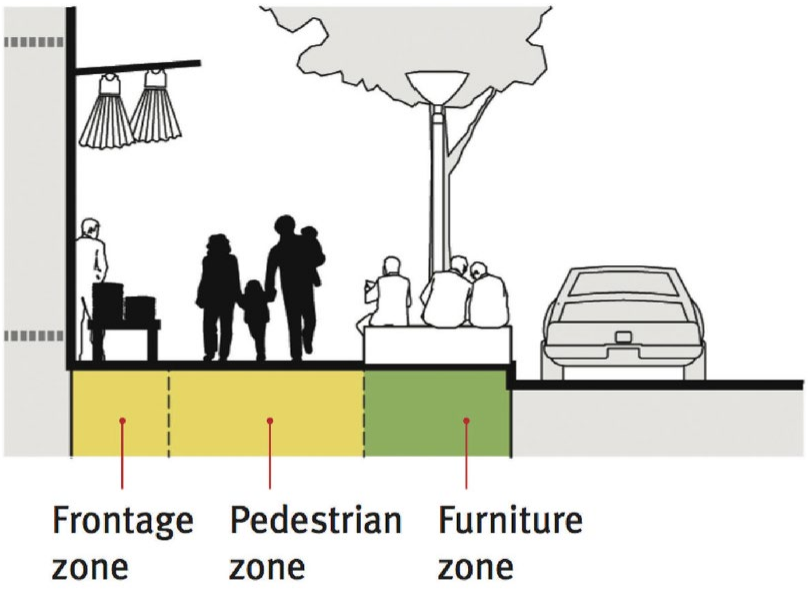


Figure 12: Sidewalk design incorporates different zones to reduce conflict of uses (Moges, 2020)

(3) As shown in Figure 7 and 8, lack of pedestrian walkways and access for non-motorized vehicles is another contributing factor for traffic congestion. 53% of the streets in the city do not have safe pedestrian paths. Therefore, it is important to focus on walkability in the city. Especially, since the primary mode of mobility in the city is walking at 54% share, versus 31% public transport and 15% private car. The motorized vehicle to non-motorized vehicle ratio does not necessarily translate to a 1:1 space ratio as vehicles occupy larger spatial area than any other non-motorized vehicle modes, however, it can help direct project budget and

emphasis to ensure that the walkability in Addis Ababa increases. ('Addis Ababa Transport Strategy 2021-2023').

Figure 12 illustrates a solution for pedestrian sidewalks that provide safe and smooth surfaces. It also incorporates all the different activities that take places on the streets of Addis Ababa. The furniture zone act as a buffer between motorized vehicle transportation and non-motorized vehicle transportation. The separation of pedestrian zone and frontage zone allows for designated areas for street vendors without impeding into pedestrian walkway. The width of these sidewalks can be determined by zoning, land use and street design. Furthermore, foot traffic data can be collected by adding thermal sensors or cameras at intersections, collectors and local roads to help monitor the level of foot traffic in pedestrian friendly areas. This allows the road authorities to monitor and manage the foot traffic in real time and address any changes that occur as the city grows.

5.2. Smarter traffic management solution

Secondly, using a smarter traffic management system can help alleviate the traffic condition in Addis Ababa. A traffic management system generally consists of intelligent transportations systems (ITS), a traffic control center and IoT devices such as sensors, CCTV cameras and more (Korableva et al., 2021). 'Intelligent traffic system is a data concentrated application that connects roads, communities and vehicles appropriately' (Sharma & Awasthi, 2022). An ITS manages to resolve key issues at three different levels; a community level as it helps reduce road accidents and congestion based on real time traffic, at an infrastructure administration level since incident prone and congested areas can be easily identified and maintained at cost effective and efficient manner, and finally at a commuter level as commuters can take advantage of the real time information available and select the best and most appropriate route to their destination (Sharma & Awasthi, 2022). ITS is an essential part of working towards a smarter traffic management system as it is responsible for traffic mobility through the of data integrated system. It has a wide range of applications which can majorly be categorized into six:

1. Advanced public transportation system (APTS)
2. Advanced transportation management system (ATMS)
3. Advanced Travellers Information Systems (ATIS)
4. Automated Highway System
5. Incident Management System
6. Commercial Vehicle Control (CVC)

The model below shown in Figure 13, is an architecture model for the development of smarter traffic management system consisting of the components mentioned above.

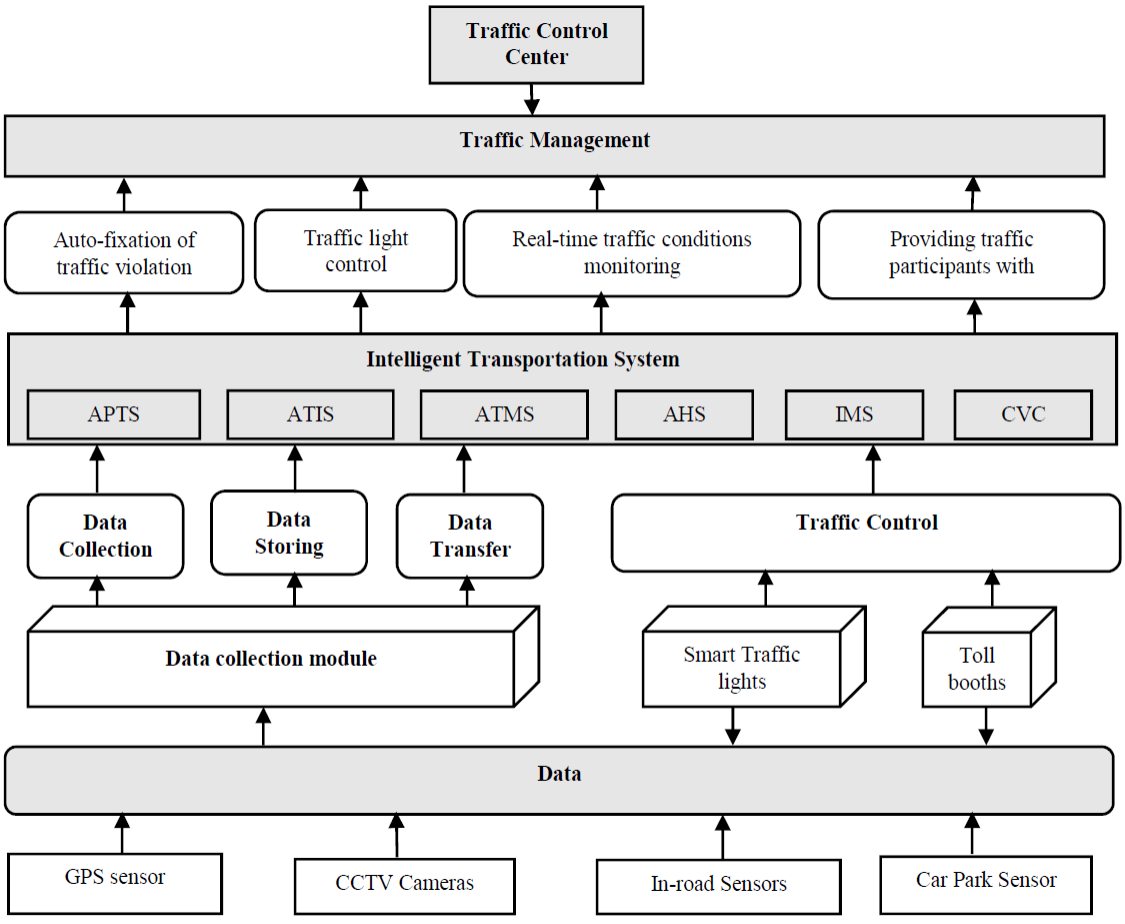


Figure 13: Architectural model for a smarter Traffic Management System (Sharma & Awasthi, 2022)

The following section provides specific solutions that can be adapted by the Ethiopian government to reduce traffic congestion based on the model in figure 13.

i) Due to lack of policy enforcement traffic signals have become a mere suggestion and are often not observed by drivers nor pedestrians. Therefore, the installation of smart traffic lights with surveillance cameras or violation detectors that have audible pedestrian signal can help enforce transportation policies. Subsequently, heavy penalties should be implemented for violators of traffic signals for both drivers and pedestrians. Vehicular violations can be detected using cameras and traffic sensors. Countries like Singapore, UAE, USA, Zimbabwe, and more, have introduced jaywalking policies and penalties. According to the English google dictionary the definition of jaywalking is to 'cross or walk in the street or road unlawfully or without regard for approaching traffic.' The penalties for jaywalking differentiate from country to country, however, it seems to be an effective method of enforcing the policy. Citations for jaywalking can be recorded on digital Identification cards (eID) and in doing so it allows the government to collect jaywalking fee per person, frequency of occurrence per area, demographic information of persons, and it can also allow for more efficient forms of payment. The use of eIDs can go beyond just jaywalking penalties as it can be linked to other benefits and public services within healthcare, The digital identification cards can also be used to detect red light violations via sensors. Auto license plate detection devices will not be advantageous in this city as majority of the time vehicles are driven by commercial or privately hired drivers. It would be advantageous for the system to be able to detect exactly who the violator is by using the same or similar technology as electric toll gate systems. The facial recognition on the camera and the chip reader will help pinpoint who was sitting in the driver's seat at the time of the incident. There have been many concerns when transitioning to digital identification cards such as data and privacy concerns, cost infringements and accessibility for all. Some of these issues have been resolved in countries that have already integrated eIDs into their system. India has had successful transition to eIDs with 90% of adults reported to having Aadhaar, the digital ID system

(Chowdhry et al.). Given the similarities in urban challenges faced between India and African countries the Indian model would 'serves as a more relatable model to understand the challenges faced by African countries than other Asian or Western counterparts' (Macdonald, 2023)

ii) The city does not have enough street parking nor parking infrastructures to support the demand. The first and most important resolution is to address the lack of parking space by land use and zoning policies. Under the advisement of the latest Structural Plan for Addis Ababa, mixed-use development has increased over the last decade to 48% of the built-up area (AACPPO). 'In a city like Addis Ababa where the proportion of street infrastructure and public transport are limited, mixed development is the most efficient solution as it decreases home-to-work trip.' The conversion of residential properties to commercial mixed-use properties, which still includes commercial activities, has significantly raised the parking demand in areas that do not have the space. Given that the mixed-use development proposal was a response to an economic issue the consequences of the proposal need to be well thought out and managed. The government should encourage private parking only structures or build government owned parking facilities. Minimum parking requirements should become mandatory requirements for developments, and it should be based on the category of the commercial activity within these new developments, i.e. banking, office, and retail. In order to develop parking policies and regulations the current and future performance needs to be considered. By monitoring and data collection the government can understand the current performance versus current demand, current issues, and predict future performance versus demand, thus allowing the government to create policies and regulation that support future demands. The monitoring and data collection can be done through the installation of surveillance cameras on the street, creating a digital parking ticketing system for street parking and smart parking systems in parking facilities.

iii) Smart parking systems include apps that provide drivers with numerous assistances. These include directions to available parking slots, real time information on events on sites, they can have integrated payment portals, and more. Such parking apps utilize IoT devices such as sensors and smartspot (communication devices) that relay information to the smartcloud. The data gathered and uploaded to the smartcloud is then linked to a geographic positioning system (GPS) creating useful information for drivers and parking facility owners. This parking solution will help create efficient traffic flow and reduce the time spent looking for parking slots (SmartSpot gateways)

iv) Drop off and pick up locations for para-transit transportation also need to be monitored and regulated. The slow-down of traffic due to para-transit vans causes major delays. The lack of discipline can be addressed by creating strict policies and consequences for disturbances like double parking, parking too far from the curb side, and illegal parking. The initial process of new regulations should be publicly announced to raise awareness, through various channels. Once enough time has passed for the circulation of the new amendment, authorities can initiate penalties to hold people accountable for causing traffic slowdown. This policy enforcement can be done using a combination of digital and manual efforts. To digitally enforce pick up and drop off policies the government can use the same monitoring method used by electronic scooters like Lime. Lime is an electric scooter company that has incorporated a new zone detecting technology that utilizes GPS to pinpoint the precise location of their scooters. They then use geofencing system 'encouraging more responsible rider behavior and enforcing local regulations' (Lime Introduces New Geofencing Technology, Setting Industry Standards For Scooters, 2020). Similarly, the Ethiopian government can use geofenced zones to enforce disciplined drop off and pick up culture. This system can be linked to a monitoring system where fines can be automatically issues to the driver registered to the para-transit van.

v) Cities like New York, Seattle, and Boston have launched the use of citizen driven apps that allows residents and visitors to report issues like potholes, graffiti, abandoned vehicles and more. Given that we have found response times to create major slow down for motorized vehicles, such apps can be utilized to help create a faster response time as it enables better and more transparent platform of communication. In conjunction with the police stations Addis Ababa Road Authorities can develop a similar app that allows drivers to report potholes, abandoned vehicles, dead animals, accidents and any other issues that are causing traffic congestion. These reports can include pictures, GPS locations, and comments for more detailed information. The app can then alert the authorities, in real time, who can then deploy the necessary resources to rectify the situation as soon as possible. The app can also collect all data and information on all issues reported. The collected data can include the type of incidences, the frequency and the response times. All of which can help the government understand reoccurring issues versus rare, and anomalies. The analysis will help develop long-term solutions, quicker response times, and better road maintenance. For instance, Addis Ababa roads suffer from potholes due to debris from construction waste vehicles, weather and poor road construction. The app can help track the occurrence of potholes, how long it took to repair them, and the responsible contractor for quality control. Since the success of the app relies on the use of smart phones it would behoove the government to create an automated system that will allow non smartphone users to utilize the same automated reporting opportunity via cellular networks. Alternatively, the app can also provide a channel of communication for incidents and traffic slow down reports and provide alternative routes to avoid congestion and terrible road conditions.

Chapter 6 Conclusions

In conclusion, Addis Ababa is not prone to the traffic congestion issues that have become an urban crisis worldwide. However, the majority of reasons for traffic congestion come from being a part of the developing world. Traffic congestion in Addis Ababa and other urban areas in Ethiopia are due to unplanned and poorly built infrastructure, lack of driving discipline caused by lack of policy enforcement, lack of alternative means of transportation, lack of parking facilities, and the sharing of car lane with non-motorized vehicles, pedestrians, and animals. Based on the data and the analysis we can see that these contributors have caused daily 15-minute traffic delays and more, outside of typical rush hour windows. They are difficult to track and predict, leaving people idle on the road. Furthermore, the traffic delay can be exacerbated by additional factors such as traffic accidents and potholes and take time and resources to be resolved. Given the low car ownership rate in the country daily traffic delays can be evaded if these prominent issues are solved.

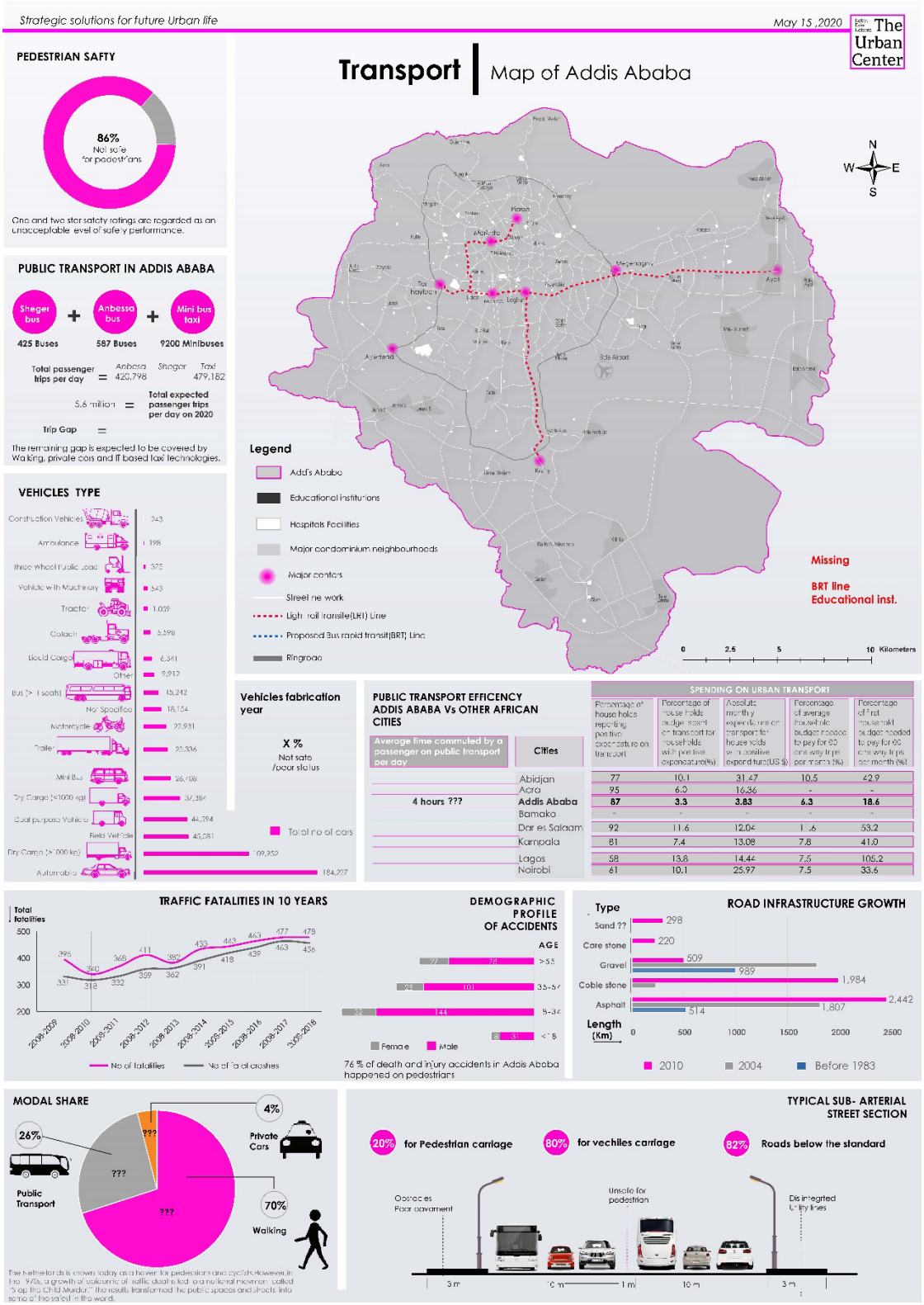
Most of the issues disturbing the traffic system in Addis Ababa remain withing the urban planning boundaries, primarily relating to physical infrastructure and urban policies. Most of these issues have already been resolved in other countries.

As described in chapter 5 the recommendation for alleviating traffic congestion is a multilayered solution that combines the improvement of physical infrastructure, urban mobility policies and digitization of systems. Given the research and data collected it is evident that Addis Ababa, Ethiopia lacks the physical infrastructure to meet the mobility demands of the city. Therefore, first and foremost it is important for the Road Authority to make sure the city makes plans to meet the mobility requirements of the city for all modes of transportation available now and anticipated for the future. This will include the four-lane hierarchy design, dedicated emergency shoulder lanes, non-motorized vehicle lanes, and pedestrian and street vendor zones. The management of mobility can be sustained using IoTs such as surveillance cameras, sensors, and thermal sensors to name a few. Each of which needs to be connected to a cloud system to collect data. It is the collection of data and analysis of the information that can help the

government develop and mend policies to ensure compliance with law and regulations. Digitized systems like digital parking tickets and eIDs can provide effective and efficient tracking and penalty platforms for violators. Not only will the policies and penalties help create order, driving habits, mobility discipline it will also help the government collect money through fees that can be a continuous source of finance. Lastly, smartphone-based apps and replicated services through cellular network that are citizen input driven will help the government create an effective communication platform that can help dispatch resources as needed.

Appendix

Figure 14: Appendix 1 – Mapping and statistics of major services in Addis Ababa



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