



ASHESI UNIVERSITY COLLEGE

An Optimal Road Transportation Model to Facilitate Free Trade in the ECOWAS

Sub-Region:

A Case Study of Ghana, Cote D'Ivoire, Togo and Burkina Faso.

Undergraduate Thesis

By

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Declaration

I hereby declare that this dissertation is the result of my own original work and that no part of it has been presented for another degree in this university or elsewhere.

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I hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by Ashesi University College.

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Abstract

Ecowedas, as part of its key policies, promotes free trade among member countries. The benefits devised from this policy, though immense, cannot be fully realized by member countries if there is no free movement of goods and services. Thus, the need for an efficient and cost-effective transportation system. This is what we termed as an optimal road transportation model.

The paper therefore, sought to identify the most efficient road transportation routes in terms of shortest distance that could be used to facilitate free trade in the sub region, what are the main challenges facing the road transportation in the ECOWAS sub-region and how these have impacted the free trade among the member states.

Therefore, to achieve optimality, the paper employed two algorithms, Simplex method and the Dijkstra's algorithm. The paper considered road networks in four-member countries namely; Ghana, Togo, Cote D'Ivoire and Burkina Faso. These road networks comprised of both inter and intra routes among these countries on which these algorithms were built to come up with an optimal road transportation system.

The model and the Dijkstra's algorithm were able to come up with a network model that could enhance movement from one country to another. For instance, if there were goods being transported from Nigeria to Cote D'Ivoire through Togo and Ghana they would take these routes: Kara - Sokode - Atakpame - Tsevie - Lome - Aflao - Tema - Accra - Capecoast - Takoradi - Elubo - Abidjan - Divo - Yamoussoukro - Bouake - Korhogo – Kaouara in Cote D'Ivoire,

Keywords: Free Trade, Road Transportation Model, Shortest Path, ECOWAS

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List of Acronyms

ECOWAS – Economic Community of West African States

WA – West Africa

LP – Linear Programming

ETLS – ECOWAS Trade Liberalization Scheme

CET – Common External Tarif

MP – Mathematical Programming

DFS – Depth-First Search

BFS- Breadth-First Search

WTO – World Trade Organization

TFAF – Trade Facilitation Agreement Facility

CHAPTER I: INTRODUCTION

1.1 Background

“The ECOWAS (Economic Community of West African States) Treaty of 1975, revised in 1993, established a regional free trade area known as the ECOWAS Trade Liberalization Scheme (ETLS)” (Lori Brock, 2009). There were many terms in this agreement formalized through numerous Protocols, and Decisions among them was; free movement of persons, goods, and vehicles within the 15 ECOWAS Member States. The treaty emphasized that goods traded and transported through the region were duty-free, and this implied that in some cases, there is no need for any certificate of origin. The ETLS was to ensure effective implementation of these protocols and eliminate all tariffs on regionally sourced inputs, reduce the cost and time of moving products throughout the region as well as harmonizing tariff levels for goods of non-ECOWAS origin to promote a transparent and consistent application of tariffs across the region (Lori Brock, 2009).

Some of the Member States in ECOWAS include; Benin, Cabo Verde, Burkina Faso, Cote d'Ivoire, Liberia, Mali, Gambia, Guinea, Ghana, Guinea-Bissau, Togo, Niger, Senegal, Nigeria, and Sierra Leone. As the name suggests, these are countries located in the Western African region. These have cultural, geographical bonds and similar economic interests (ECOWAS, Member States, 2017). The region is bordered by the Atlantic Ocean in the Western and Southern parts and it is also boarder by the Sahara Desert in the northern part.

There was an effort by ECOWAS to link up 12 of these West African countries in a project named “The Trans–West African Coastal Highway” and this was aimed at linking the coastal nations. This runs from Mauritania in the north west of the

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ECOWAS region to the east in Nigeria but having feeder roads that would attach the land locked countries to this highway, that is Mali and Burkina Faso (Madamombe, 2006). This has also taken different forms or names from the various organisations or bodies such as ECOWAS and UN and these are; Lagos–Nouakchott Highway, Nouakchott–Lagos Highway, Dakar–Lagos Highway, Lagos–Dakar Highway and Trans-African Highway 7 in the Trans-African Highway network.

According to ECOWAS (2016), the total trade of the region has averaged 208.1 billion US dollars. The exports are projected to be approximately 137.3 billion US dollars while the imports total to approximately 80.4 billion US dollars. It is also stated that “some of the main active countries in the trade are Nigeria, this alone accounts for approximately 76 percent of the total trade and it is followed by Ghana with only 9.2 percent and Côte d’Ivoire contributing 8.64 percent” (Economic Community of West African States [ECOWAS], 2016). The figures indicate how relevant and developmental the trade is to the region and the role it plays on the world economy. “The surplus of the trade in the region is estimated at about \$47.3 billion and it is mainly attributable to Nigeria with \$58.4 billion and Côte d’Ivoire with \$3.4 billion, unfortunately, all the other countries have a deficit in the trade balance” (ECOWAS, 2016).

Furthermore, the vital feature of the ECOWAS Free Trade Area which is driven by the ETLS focuses on the removal of all tariff and non-tariff barriers to trade. ECOWAS believes that once the benefits of the ETLS for West Africa are fully implemented, this would lead to greater economic growth, creation of more jobs and lowering consumer prices in the region (ECOWAS Commission and USAID West Africa Trade and Hub, 2017).

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As a result, research was conducted by ETLS in partnership with USAID West Africa Trade Hub. They carried this out by undertaking a gap analysis of the ETLS in order to identify which aspects of the ETLS protocols are being implemented in individual Member States, determine those which are not, as well as those the public and the private sector shareholders interpret as the obstacles to implementation region (ECOWAS Commission and USAID West Africa Trade and Hub, 2017). The purpose of the research among these Member State countries was to give a more definite situation in the region and how recommendations and improvements can be made.

In the same line, according to the World Trade Organisation(WTO), when talking about international trade there are some factors such as bureaucratic delays that usually pose a burden to traders when transporting or moving goods across borders of different countries (World Trade Organisation [WTO], 2017). WTO therefore presented a technique that would be used to boost international trade and that is trade facilitation. “Trade Facilitation is the potential to deliver goods and services on time, at the least possible cost and with adequate safety and security emerged as an essential requirement for global trade” (Zaney, 2017). Research shows that the main objective of Trade facilitation is to ease the way trade is conducted across borders in terms of exports and imports at a relatively cheaper cost. Achieving this involves simplification, modernization and harmonization of the procedures and formalities for the exports and imports (WTO, 2017).

In order to foster trade facilitation in both developed and developing countries, the WTO negotiated on a land mark, Trade Facilitation Agreement (TFA) that it introduced at their 2013 Bali Ministerial conference (The Trade Facilitation Agreement, n.d). Picking a leaf from the ECOWAS trade policies, WTO members are seeing to it that this gets implemented. Just like any agreement or treaty, TFA had

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provisions that were aimed at expediting the movement, release and clearing of goods. These would subsequently lead to potential benefits for both the government and communities. Hence, it would be a good recommendation for fostering the ECOWAS free trade.

On the other hand, Haksever, Render, Russell, and Murdick, (2000) made mention that at the heart of many service operations lies the scheduling of customer service and the routing of service vehicles. They give instances that some services, such as school buses, public health nursing, and many installation or repair businesses, service delivery is perilous to the performance of the service while as for other services, such as mass transit, taxis, trucking firms, timely delivery is the service (Haksever C., 2000).

The main objective of why routing and scheduling problems are important and worth exploring is because they enable us to minimize the total cost of providing the service. In terms of trade, it is usually a company's objective to provide services or products to its customers at the lowest cost possible. Research by Ragsdale (2007) supports that, in the quest to carry out this transportation analysis, and coming up with the best transportation decisions, then the best methodology to use is the network modeling and this is mathematically known as Mathematical Programming (MP) (Ragsdale, 2007).

“Mathematical Programming is a field of management science that fields the optimal or most effective way of using limited resources to achieve the objectives of an individual or a business” (Ragsdale, 2007). This has many techniques that are used in solving Mathematical Programming problems such as; Mixed-Integer Programming, Integer Linear Programming, Mixed-Integer Quadratic Programming and Linear

Programming (LP). In this paper, the focus will be more on the Linear programming technique.

According to Ragsdale (2007), Linear Programming is a technique which involves creating and solving optimization problems with linear objective functions and linear constraints (Ragsdale, 2007). Practical example of the LP model by Lewis (2008) shows that “LP was developed during World War II when a system with which to maximize the efficiency of resources was of utmost importance” (Lewis, 2008). There are several assumptions that are implicit in Linear Programming problems such as; proportionality, additivity, divisibility, and certainty. The LP is desired among the other MP techniques because it is simple, widely used to show how real-life problems can be solved as linear programs and it has a wide range of real life applications such as transportation, business, health science, agriculture and nutrition. This paper, sought to focus on how to build an LP model for facilitating free movement and free trade among the ECOWAS sub-region.

1.2 Description of Research Problem

There are several challenges that might be affecting the free trade in the ECOWAS region, however one of them is the lack of trade facilitation. This explains why the region has not been able to achieve its aim of being integrated into the multilateral trading system (Ayamgha, 2016). One of the major trade facilitation that has been put in place is the transportation. In this line, ECOWAS put in place a vigorous transport programme that was meant to facilitate the movement of persons, goods, and services in the region (ECOWAS, 2016). This was undoubtedly aimed at facilitating the trade by leading to a greater integration in line with the development policy of the community.

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However, discoveries made showed that there were delays, and costs involved in the movement of persons and goods across the region. These delays and unreliable costs discouraged the regional trade as they resulted into an increase in the cost of doing business in West Africa region (ECOWAS Commission and USAID West Africa Trade and Hub, 2017). According to Ahmed (2009), this poses a big threat to the economy of the region because most of the inter-country trade is also undocumented and casual, hence leading to loss of revenue for the countries (Ahmed, 2009).

These delays have been caused by the inadequacy of transport infrastructure and services in West Africa (ECOWAS, 2017). Deen Sarray argued that, the road network in the region remains inefficient and poorly linked (as cited in Jakob Engel and Marie-Agnès Jouanjean, 2015, p. 4). The major cross-border corridors in the region are now entirely paved, however they are still subject to roadblocks and requests for bribes by customs and immigration officials and this makes the transportation problem intense for facilitation the free trade (Engel & Jouanjean, 2015).

On the other hand, looking at it from an economic point of view, once there is a high demand for a particular product and the supply is low, then this would lead to an increase in the price of the products. Hence, daunting local consumption in the short or long run. In the same line, the delays could also invigorate the country sales men to shift their buying options to opting for other suppliers that are outside the region who would deliver the commodities on time and this would eventually make this potentially economic trade irrelevant and ineffective.

Therefore, due to this transportation challenge, this in no doubt makes the market access undesirably, and this is mainly caused by the geographical distance between the producers and consumers, as well as the availability and quality of the connecting infrastructure. Research by Torres and Seters (2016) shows that, apart from

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the main roads, absent or poor road infrastructure in rural areas is even worse of a problem. They attributed this to the road density in West Africa which is relatively low as compared to other developing regions and this explains why the rural communities continue to be inaccessible to all-season roads in the developing world (Torres & Seters, 2016). Although, this problem differs within the countries in the region take for instance Ghana and Nigeria have better road systems as compared to the other countries, nevertheless this still raises a huge threat to the trade because the trade cannot be effective with only two out of the fifteen countries having better road systems.

To add, the transportation problem is greatly linked to several factors that are affecting the free trade across the regions that is why some of the instruments that must be put in place to enhance this include; removal of total exemption of taxes and import duties, having no quantitative restrictions and having compensation for loss of revenue on items being imported. Once some of these are implemented, then coming up with an efficient transport model to facilitate this free trade would be an added advantage to the trade.

Furthermore, the intra-regional trade is also greatly fraught by the high costs of moving goods by roads or rail within the region and this is as a result of poor infrastructure and governance of the transport sector. This mainly affects the producers in rural areas and the traders. The transport prices incurred from the farmgate to the primary collection in terms of per ton kilometer are usually higher than those incurred when moving from the rural wholesale and this could be three to five times higher as compared to those that are in the countries capitals (Torres & Seters, 2016).

Torres and Seters (2016) in their report noted that, as investments in transport infrastructure are crucial, this does not necessarily render to lower transport costs, and so road governance and structural issues ('software') in the transport sector also

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influence transport prices. To sum it up all, the ETLS has tried to implement the free trade policies but despite all these potential trade benefits flowing from these policies, intra-community trade still remains low (Ike & Gaarlandt, 2016). This is because several factors have been identified as impediments to free trade across the region such as continued existence of tariffs and non-tariff barriers in the countries, among others. Therefore, there is need for identification of which routes they can use to maximize their free movement and trade in terms of distance. Hence, determining the shortest distances between the different exit points of the countries under study and how these connect to the various market centers in the ECOWAS region.

1.3 Research Question (s)

This paper seeks to answer the following questions in order to give a proper understanding of the topic that is being researched on and some of these are:

1. What are the most efficient routes that are being used to facilitate free trade among these ECOWAS countries?
2. What are some of the transportation challenges that are being faced in the ECOWAS region and how they affect the free trade?
3. Can an LP model be constructed to help optimize free trade in the ECOWAS region?
4. Is there an existing system/ Algorithm that can be used to find an efficient transportation model?

1.4 Research Objectives

The following objectives should be achieved at the final part of the dissertation. The objectives of the research are:

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- To identify the most efficient road transportation routes in terms of shortest distance that can be used to facilitate free trade in the region.
- To identify and describe the road transportation challenges in the ECOWAS sub-region and how they impact free trade.
- To come up with an efficient road transportation model for to facilitate free trade across these ECOWAS countries under study.
- To come up with an algorithm that can be used to determine the most efficient routes in terms of shortest distance.

1.5 Research Relevance

According to the Earnest and Young Tax Insights, ECOWAS has in the past almost 20 years been trying to promote the free movement protocol which establishes the right of community citizens to enter, reside in and establish businesses within member states (Ike & Gaarlandt, 2016). Brock, Omoluabi and Dusen (2009) noted that the ETLIS was to ensure effective implementation of these protocols to eliminate all tariffs on regionally sourced inputs, reduce the cost and time of moving products throughout the region. (Brock et al.,2009).

Most member states have substantially implemented visa-free movement and free vehicular movement. Therefore, establishment of a shortest path would enhance the free movement and trade by reducing delays and costs involved in the transportation of both goods and people. Since the delays caused by inefficient transportation networks lead to negative effects such as; wastage of perishable goods, creation of shortages at the demand points hence resulting in increase in prices that would discourage the local consumers.

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More to that, one of the achievements of ECOWAS has been construction of highways that link major cities across the region. Take for instance the Lagos-Abidjan intra road network that runs from Elubo in Ivory coast through Aflao in Ghana to Lagos in Nigeria, as well as completion of the completion of the Nouakchott-Lagos road network (Nsikan, 2017). This gives us the fair understanding of the existence of these road networks.

Consequently, to counteract this problem there needs to be development of an efficient transportation model that is in terms of determining shortest paths that would enhance this free trade. This would in a way play an important role in promoting and boosting the free trade and movement in the region. The assumption made here is that the transportation model would point out the various efficient routes in terms of shortest distance that can be used by the member states citizens as a guide in making decisions connecting to transportation of their products across the region.

In conclusion, the study will not only contribute to the existing knowledge about the ECOWAS free trade and improvement of the free trade in the region but will also aid entrepreneurs in making business decisions linked to transportation of their products across the region. Since this would enable them to reduce their transportation costs. The trade also has a very high potential in developing the economy of the region once embraced very well. Therefore, I believe coming up with this efficient road transport model (network) will not only minimize the distribution costs for the countries, but also create easy access of the products by the different customers when needed as well as promoting tourism in the region.

CHAPTER II: LITERATURE REVIEW

2.1 Introduction

This chapter explores several contributions that have been done regarding the topic of study. The chapter is subdivided into five sub-sections. The first sub-section focuses on the Economic implication of transport networks to the Economic development of a country. The second sub-section explores how transportation flow problems have been tackled by other scholars. The third one focuses on the Mathematical Programming Model problems and how they have been used by various scholars to make transportation and business decisions. The fourth one looks at Shortest paths algorithms that have been used to determine the maximum and minimum optimization models in a network problem. The last sub-section focuses on how to find the Cost-effective routes in a Network Problem.

2.2 Economic implication of transport networks to Economic development of a country

Several scholars have made some extensive research in the area of transportation in trade and they have come up with different deductions about the implication of transport networks in the economic development of a country. Ghani (2015) pointed out that infrastructure is said to be an essential ingredient in economic growth and development. The transport infrastructure is very instrumental in facilitating a cheaper, more efficient movement of people, goods as well as ideas across places (Ghani, 2015). It further leads to an enhanced distribution of economic activities and their development across various regions. It is also reported that inadequate infrastructure is a very perilous obstacle to sustained growth.

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However, Ghani (2015) made mention that the literature about the economic impacts of transportation networks in developing countries is relatively small as compared to its importance, though it is gradually emerging. It can be explained that, the industrial decentralization in the Republic of Korea was attributed to the massive transport and communications infrastructure investments there (Ghani, 2015). Thus, this accounts for the tremendous economic development in the country as compared to the countries that have not really invested into their transportation system.

Furthermore, other literature shows how effectively these transport networks have been implemented to enhance economic development in other continents and so the question is whether these can work effectively and efficiently in Africa. Wang and Yeo (2017) in their paper made mention that, increase in trade in any inter countries would call for an efficient intermodal route for transporting cargo. This explains why there was need for development of a transport model in Korea to facilitate the trade from Korea to Central Asia (Wang & Yeo, 2017). This reveals a consensus between these two writers and Ghani (2015) about transport models in economic development.

However, the intermodal routing for long-distance transportation faces several operational challenges such as; customs clearance, track gauge differences and climate limitations. Wang and Yeo (2017) notified that, cost is noted to be the most crucial factor that is considered by logistic companies when they are to select a transportation route, then followed by how reliable the route is, the capability of the route, the total time it takes to cover that route and security (Wang & Yeo, 2017). All these factors have an economic implication on the trade and so they can either enhance or hinder it. Since cost is noted to be the most crucial of all these factors, this demonstrates how relevant transportation is in trade. Therefore, to build any network model all the above factors must be considered.

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To add, according to the World Trade Organisation(WTO), (2017), when conducting a study about international trade there are some factors such as bureaucratic delays and “red tape” that usually pose a burden to traders when transporting or moving goods across borders of different countries (World Trade Organisation[WTO], 2017). Therefore, WTO presented a technique that could be used to boost international trade and that is trade facilitation. “Trade Facilitation is the potential to deliver goods and services on time, at the least possible cost and with adequate safety and security emerged as an essential requirement for global trade” (Zaney, 2017). Investigations made depict that the main objective of Trade facilitation is to ease the way trade is conducted across borders in terms of exports and imports at a relatively cheaper cost. Achieving this involves simplification, modernization and harmonization of the procedures and formalities for the exports and imports (WTO, 2017). The study by WTO also noted out some of the factors that affects companies in terms of transportation as seen in the paper by Wang and Yeo (2017).

Furthermore, to foster trade facilitation in both developed and developing countries, the WTO negotiated on a land mark, Trade Facilitation Agreement (TFA) that it introduced at their 2013 Bali Ministerial conference. (World Trade Organisation & Trade Facilitation Agreement Facility, n.d). Picking a leaf from the ECOWAS trade policies, WTO members are working around getting the TFA implemented. Just like any agreement or treaty, TFA had provisions that were aimed at expediting the movement, release and clearing of goods. These would subsequently lead to potential benefits for both the government and communities. Hence, it would be a good recommendation for fostering the ECOWAS free trade.

In the same line, in the quest to bring about economic development growth by ECOWAS in the West African region, there was a proclamation of the Protocol on Free

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Movement of Persons, Goods and Services (Ayamga, 2014). This was mainly geared towards the promotion of intra-regional trade, as well as bringing about interaction among the community citizens. Unfortunately, this has not been fully achieved due to a couple of reasons from the different member states such as tariffs. This doesn't rule out the fact that there is high potential in the trade and putting necessary measures in place to facilitate this trade would be of immense importance to the region. Therefore, in as much as there are such hinderances to the trade, trade is still ongoing among the different member state countries and this needs not to be overlooked. Take for instance, there are trade transactions between Cote d'Ivoire and Ghana and that is why in the general market and trade statistics of Cote d'Ivoire, Ghana and Nigeria are listed as some of its trading partners (International Monetary Fund [IMF], 2017).

2.3 Network Flow problems

Network Flow problem can be defined as a network model that was designed to help solve several practical decision problems in businesses. According to Ragsdale (2007), "Network Flow problems are linear programming problems with a main objective of finding an optimization solution either in terms of minimizing costs, time or distance or maximizing returns (profits) in a particular decision" (Ragsdale, 2007). Network Flow problems usually share some common features and they can be either described or displayed in a graphical form known as a network. These take several forms such as; transshipment problems, shortest path problems, transportation/assignment problems among others.

A study by Ahuja, Magnanti and Orlin (1991) showed that literature about Network Flow Problems is extensive. This can be supported by several advancements in Network Flow Problems and as a result, for the past over 40 years researchers have made continuous advancements to algorithms for solving several categories of Network

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Problems (Ahuja, Magnanti & Orlin, 1991). They also noted that numerous techniques were proven to have been very successful in permitting researchers to make some recent contributions: such as “(i) scaling of the problem data; (ii) improved analysis of algorithms, especially amortized worst-case performance and the use of potential function, and (iii) enhanced data structure” (Ahuja et al., 1991).

In addition, the above advancements were done in the quest to focus on designing a faster algorithm from the worst-case perspective. The scope for these algorithms was only to cover the fundamental problems of the shortest path problem, minimum cost flow problem and maximum flow problem which this paper seeks to tackle too (Ahuja et al., 1991).

Ahuja et al., (1991) made mention of algorithms that were developed to solve the different problems such as a radix heap algorithm for solving the shortest path problem. This was written in the C++ programming language and it works well with other algorithms like the common shortest-path algorithm called Dijkstra Algorithm. For maximum flow problem a Preflow push algorithm is used and for the minimum cost flow problem, a Pseudoflow push algorithms is used (Ahuja et al., 1991). Therefore, since this paper is trying to tackle a minimum cost flow problem, then the Pseudoflow push algorithm would be best. However, there is uncertainty about its credibility due to the advancements that have taken place in technology with almost 2 decades ever since it was invented. Their paper was also limited to a few Network problems as compared to Ragsdale who looks at a couple of Network Flow problem solving techniques that give a researcher a wide range to choose from. The merit about Ahuja et al., (1991), is that they justified their use of a particular algorithm for a particular Network Flow Problem.

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Hoppe and Tardos (2000), wrote that transport modeling has been very crucial in the field of Network Problems since the 1940s. They raised a strong point of a question that has been ignored by researchers in the Network flow theory and this is usually asked by kids to their parents, “Are we there yet?” (Hoppe & Tardos, 2000). This usually requires parents to consider time in their planning for a trip. This drives a very important concept of dynamic networks which is the quickest transshipment problem model. Dynamic networks consist of graphs with capacities and transit times on its edges (Hoppe & Tardos, 2000)

Furthermore, the Dynamic Network Problems are said to have been introduced by Ford and Fulkerson (1962), and they considered this network to have a single source and a single sink. As notified by Hoppe and Tardos (2000), there have been improvements in this theory and that is why the Dynamic Network is made up of several sources and sinks and each source has got a specified supply as well as each sink having a specified demand. However, the challenge with this model is having to send the exact amount of capacity out of each source and into each source at the minimum overall time (Hoppe & Tardos, 2000).

In the same line, Atamturk and Zhang (2007) presented a very crucial concept known as the “two-stage robust optimization approach which was used for solving Network Flow Problems. This approach was designed to solve Network Flow Problems that have uncertain demand. This relates well to the Network problem being studied in this paper about the transportation among the four chosen ECOWAS countries. The demand in the different countries for the commodities from another country is not known. This comes as an advantage to the person working on a Network model with uncertain demand. It also allows someone to come up with a less conservative solution as compared to the single-stage optimization as the person will have allowed a “budget

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for demand uncertainty” (Atamturk & Zhang, 2007). However, even though the two-stage approach has its own advantage, this at times comes with a price which makes it significantly harder than the single-stage optimization (Atamturk & Zhang, 2007).

On the other hand, in this present era, technology is being used to enhance faster and efficient ways of solving problems. Klingman, Napier and Stutz (1974) gave a simplified description of a certain computer program that was developed, implemented and was available for generating a variety of feasible Network problems in addition to a set of benchmarked problems that are derived from it. This program was called NETGEN, and the authors stated that “It is a program for generating large scale capacitated assignment, transportation, and minimum cost flow network problems” (Klingman, Napier & Stutz, 1974).

Discovery of this technology was a great milestone in the Network Flow problems topic as this made solving these problems more effective and efficient. In that regard, one scholar Owen (1962) highlighted the importance of technology. She made mention of how developed areas had two advantages over the under-developed ones in the nineteenth century and the most crucial of these was possession of technical knowledge and applying it efficiently (Owen, 1962).

The NETGEN code worked in a way that it could generate capacitated and incapacitated transportation and minimum cost flow network problems as well as assignment problems. Klingman et al., (1974), gave solutions to over 40 network flow problems which were varying in size that is from 200 nodes to 8,000 nodes and 1300 arcs to 35000 arcs. This illustrates the efficiency of the NETGEN program. However, there have been a lot of advancements that have taken place in technology ever since this program was invented, and this implies that there is a less likelihood for this innovation being very efficient presently (Klingman et al., 1974).

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To add, one of the limitations with this computer program is that in the 70s, there might have been fewer road networks and so this meant fewer nodes at arcs in the network model as compared to now when there are quite several road networks, resulting in more nodes and arcs. However, we cannot just focus on the limitations without appreciating the success of the program. This is because it saved both users and developers from having to evaluate codes as to their capacity as it used to be in the earliest computational experiments of Network computer codes.

2.4 Mathematical Programming Model

This sub chapter looks at a review of literature about scheduling problems that are solved by Mathematical Programming techniques. This is to provide more insights on some of the existing techniques and algorithms that have been implemented in solving transportation problems.

Ragsdale (2007), made mention of the fact that having to make decisions of how we can best utilize the limited resources available to us or any business is a universal problem. This usually calls for a proper allocation of these resources in a way that can maximize profits or minimize costs. Mathematical Programming (MP), which is also known as Optimization was defined as, “a field of management science that finds the optimal, or most efficient, way of using limited resources to achieve the objectives of an individual or business” (Ragsdale, 2007).

Mathematical Programming is a problem-solving technique whose objective is to determine the value of the decision variables in a problem which will be used to maximize or minimize the objective function while satisfying the constraints. The MP includes packages such as “LINDO, MPSX, CPLEX, and MathPro” (Ragsdale, 2007), that can be used to solve Network problems that cannot be solved by Spreadsheet, and

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this is mainly because indeed some Network problems are complex to be solved using the Spreadsheet.

However, Korley (2010) in her thesis worked on developing an optimization model for efficient distribution of petroleum products and this was made for Tema Oil refinery. She made a claim that enhancing the existing transportation procedures would be a significant cost saver to the government. In implementing this model, she formulated a linear programming model and used solver which is an in-built optimization tool in Microsoft EXCEL to solve it (Korley, 2010). This example gives a proper representation of a transportation network model that was solved using spreadsheet. And it also doubles as an example for implementation of MP in the African setting as a lot of literature has been written about network models outside of Africa.

Furthermore, spreadsheet in its quest to solve Network problems that are not so complex employs the simplex method. According to the MathWorld website, the simplex method is defined as a method for solving problems in linear programming (Carreira-Perpiñán, 2017). Spreadsheet is made up of other problem-solving methods such as, Evolutionary, GRG Nonlinear, however the simplex method is desired among the three methods in solving optimization problems, more especially the shortest path problems with the help of the solver tool.

Just like other papers reviewed suggested, the main objective of any method is to make problem solving most efficient, and so the simplex method too is efficient in making several iterations for various constraints. This aligns with another study that was made about the simplex method qualifying it to be the most efficient solutions method in linear programming for solving problems involving more than two variables or those with many constraints (Cengage, 2017). It is better to use solution methods that are adaptable to computers because there is a relatively high percentage of people

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using computers today as compared to the recent times, hence making any solution method that used computers more efficient and effective in problem solving.

Stearns (1964), in his paper, described an MP model that was developed to facilitate the study of the general strategic movement problem in the U. S civil defense program. This model was meant to be applicable in planning strategic movement problems and make them optimum. This is because there were a lot of nuclear attacks in the U.S and so there was need to minimize the number of expected nuclear casualties in the population (Stearns, 1964).

In this model, one had to specify an attack area which was divided into sectors which included several population centers and their different neighboring areas. The author used a very exquisite term *vulnerability*, “The term vulnerability is defined here as the probability that an individual will be casually during the post-attack period” (Stearns, 1964). Just like any other model, the main objective of this model was to optimize the strategic movement plans, and this was to be achieved by making sure that the post-attack casualties that were caused by the nuclear weapons effects are minimized.

Another paper by Prager (1965), explored a very interesting concept too of incorporating two fields of Mathematical programming and theory of structures. He stated that “In fact one of the earliest examples of a linear optimization in the literature concerns a structural problem” (Prager, 1965). The examples in this paper were mostly concerned with flows in networks and the mechanical representation of a simple type of structure. One of the models in this development was the maximal flow problem. This was used to solve several economical and sociological problems, and he gave an example of a commodity that is produced in certain cities (plants) in a given amounts, is then consumed by consumers in a given amounts in other cities (markets) (Prager,

1965). This calls for attachment of arcs and nodes and various capacities on this structure to get a full picture of the network. This exactly emulates what the study was trying to solve in this paper about the ECOWAS transportation model.

All the authors in this subsection had their work trying to justify the use of Mathematical Programming algorithms to solve Linear programming problems in a most efficient way. As the years went by, there were improvements made in the various algorithms to solve more complex problems efficiently.

2.5 Shortest Path Algorithms

Divoky and Hung (1990) presented that minimum cost flow problems can be solved by making successive arguments along shortest paths. They also examined the implementation of shortest path algorithms. There is a need to understand that flow networks have a dynamic topology and this calls for the development of a network generator that can be used to emulate this topology. According to the Management Science research, much of the shortest path research that has been conducted in the past has focused on using certain algorithms such as stand-alone procedures (Divoky & Hung, 1990). This algorithm focuses on solving the shortest path problems with nonnegative edge weights or being a solution procedure for larger problems. Some of the algorithms have greater theoretical efficiency or practical efficiency and this is one of the major research areas for Management Science

Unfortunately, there has not been much examination for using subroutine procedures for larger problems as compared to the stand-alone case. Furthermore, Divoky and Hung (1990) presented that the efficiency of application of any shortest path algorithms is not only dependent on the efficiency of the algorithms themselves, but also the method that is used to exploit the structure of the network that is made from the solution of the larger problem (Divoky & Hung, 1990). In this instance, the network

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is made up of arcs with nonnegative weights and a subnetwork where the nodes are connected to zero-weight arcs.

Furthermore, the transportation algorithm is said to have the same steps as the simplex method of finding the shortest path. But on the other hand, the transport algorithm can organize the computations in a more convenient form as an added advantage of having a special structure of the transportation model. Some of the steps involved are; “Determining a starting basic feasible solution, Use the optimal condition of the simplex method to determine the entering variable from among all the non-basic variable. If the optimality condition is satisfied, stop and Use the feasibility condition of the simplex method to determine the leaving variable from among all the current basic variable, and find the new basic solution.” (University of Babylon, 2017).

The Simplex method is a very practical method of finding shortest paths and it plays a key role in finding an optimal solution for multivariable problem (Trick, 2017). This algorithm can be used to examine the corner points similar to those of a graphical solution, but this algorithm does it in a methodical fashion making it easy to attain the best solution of a shortest path (Online Tutorial 3, n.d). This algorithm comes on computer programs such as Spreadsheet that are almost accessible to all personal computers and these are used to make the simplex calculations for the computer user which makes it a very reliable algorithm for finding shortest paths.

In addition, there is need to understand that when using the Simplex method algorithm there is need to convert the various constraints to equations and these are usually in form of inequalities. This can be applicable in this paper in a way that it identifies the various products that need to be transported to the various regions or places and take them as constraints and convert them into equations which are solvable

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by the simplex method in a Spreadsheet in-built program called Solver. Ragsdale (2007), gives some examples; For Minimum Cost Network Flow Problems where:

$$\text{Total Supply} > \text{Total Demand}$$

$$\text{Total Supply} = \text{Total Demand}$$

$$\text{Total Supply} < \text{Total Demand}$$

Application of the Balance-of-Flow Rule at the various Nodes:

$$\text{Inflow} - \text{Outflow} \geq \text{Supply or Demand}$$

$$\text{Inflow} - \text{Outflow} = \text{Supply or Demand}$$

$$\text{Inflow} - \text{Outflow} \leq \text{Supply or Demand}$$

Examples of the Equations for the various constraints:

$$X_1 + X_2 + X_3 + \dots + X_n \geq A$$

$$X_1 + X_2 + X_3 + \dots + X_n = B$$

$$X_1 + X_2 + X_3 + \dots + X_n \leq C$$

Objective function equations

$$\text{Min: } aX_1 + bX_2 + cX_3 + \dots + nX_n$$

$$\text{Max: } aX_1 + bX_2 + cX_3 + \dots + nX_n$$

Non-zero Constraint.

$$X_1 + X_2 + X_3 + \dots + X_n \geq 0$$

2.6 Programming Algorithms

Levitin (2012), defined an algorithm as a sequence of unambiguous instructions for solving a problem. For example, in this paper, there needs to be a sequence of instructions that need to be put together to come up with a transportation model that would be used to enhance the free trade in the ECOWAS sub region. This model is a graph problem, and this is said to be one of the oldest and most interesting area in algorithmic (Levitin, 2012). Graphs are made up of a collection of points called vertices and these are connected by line segments called edges, that is why they are used for modelling transportation applications. These take various categories such as; Undirected graphs, Digraphs, Weighted graphs and Trees.

Furthermore, talking about Trees which are a connected acyclic graph, they depict an interesting property that can be used in modelling transportation models. This property shows that where there are two vertices in a tree, there is usually one single path that would be connecting the vertices (Levitin, 2012). This is very practical in a case where there are two towns that are connected by a road. Unfortunately, this would not be very appropriate in finding a shortest distance in this paper because there are alternative routes that can be used as there is not only one route connecting the vertices.

In retrospect, Levitin (2012) introduces new algorithms that is the Depth-first Search (DFS) and Breadth-First Search (BFS) that are also crucial algorithms used in processing vertices and edges of a graph systematically. The DFS traverses or searches the graph data structures by making one node a root (arbitrary vertex) or visited and then explore the other vertices in the graph before returning to the root node while ensuring that all of the vertices are connected. The BFS is also an algorithm for traversing or searching the graph data structures, just like the DFS it starts from one node (arbitrary vertex) or a root, but, it explores the neighbouring nodes first before it

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moves to the other level neighbours (Levitin, 2012). The BFS is a much better approach in finding shortest paths since it starts from the neighbouring vertices as compared to the DFS that starts from anywhere after identifying the root. This algorithm works systematically as the simplex method in Spreadsheet and so these can be used interchangeably in finding the shortest path.

In addition, Levitin described another algorithm known as Dijkstra's Algorithm which is a most widely used application for transportation planning. This algorithm focuses on single-source shortest paths problems. Single-source shortest paths problems have paths that are from a source to several vertexes in the graph and some of these usually have similar edges. Levitin (2012) also acknowledges other well-known algorithms that are used to find shortest paths such as; Floyd's algorithm which was for finding general all-pairs shortest-paths problems (Levitin, 2012). The algorithm works best in a single-source shortest path problem take for instance there is need to transport goods from one town to or country to another and these have to pass through several points or cities. This can be represented as a problem of finding shortest paths from a source vertex v , then moved to all other vertices in the graph (Yan, 2017).

Weighted graph $G = (E, V)$

Source vertex $s \in V$ to all vertices $v \in V$

The Dijkstra's algorithm is like the Breadth-First search algorithm in a way that it finds the shortest path from the source then to a vertex that is nearest to it and so on. It is also similar to the prim's algorithm as they both construct an expanding subtree of vertices and they select the next vertex from the priority queue of the remaining vertices (Levitin, 2012). However, scholars should not confuse them because they solve different problems hence make different computations. Take for instance, Dijkstra's

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algorithm compares path lengths and adds edge weights whereas the prim's algorithm compares the given edge weights. The limitation to this algorithm is that it is applicable to only undirected and directed graphs that have nonnegative weights. However, this has not retarded the algorithm from being popular in solving shortest path problems (Levitin, 2012).

2.7 Determining Cost-effective Shortest paths

Cost-effective Shortest paths were implemented in the USA and these were a growing transportation model with a special name known as “Deviated fixed route transit (DRFT)” (Yang et al., 2016). They built a GIS-based method that was to be used to identify cost-effective routes for rural DFRT. The variables considered in this method were the demand distributions, which would be the products that need to be transported from one country to another and then a road network which represents the existing roads (Yang et al., 2016).

Yang et al. (2016) made a very interesting concept of having possible routes starting at urban centres and then they extend to the various network directions in certain length increments. They identified most of the routes that fall into their desired range and are accessible to the users. Factoring in the cost effectiveness of the routes, they had to focus on making comparisons among the operating costs per passenger trip. After identifying the most cost-effective route, it is presented on a GIS map. Google maps has something like that, though it provides only the distances in terms of kilometres and the time taken to cover those distances, but it does not provide the costs per those distances (Yang et al., 2016).

However, there is something worth noting that Yang et al. (2016) made mention of in their paper. They explored that cost effectiveness is something specific to regions of a country and, so it can't be generalised, that is, some routes are cost effective when

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short in some parts or regions of the country and on the other hand some routes are cost effective when long in some other parts or regions. This poses a barrier in determining cost effective routes as it is hard to deduce certain results to work on all the routes due to these discrepancies. More still, this would also make the transportation model complex if it is required to find results for each route.

CHAPTER III – METHODOLOGY

3.1 Overview of the Method Section

This section of the study was meant to analytically discuss how the study was conducted, the various tools that were employed in the study, the sample and different sampling techniques, methods of data collection, an analysis of the collected data as well as the tools used for the analysis.

The study sought to find the optimal path for facilitating free trade among these ECOWAS sub-region countries of; Ghana, Togo, Cote D'Ivoire and Burkina Faso.

Due to the nature of the research, a quantitative method was employed, and the data collected was quantitative. This was in form of distances from one centre (city) to another in kilometres for the road network we considered in the study.

The following outlines the various subsections in the Methodology chapter and these were;

- Research Design
- Research Scope
- Study Population
- Study Area
- Sampling Strategy
- Sampling techniques
- Sample sizes
- Data collection Instrument
- Data collection
- Data Collection Procedure

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- Data Preparation, collation and processing
- Data Analysis
- Validity and reliability
- Limitations and Delimitations
- Formulation

3.2 Research Design

The Research design articulated what data was required, what methods were to be used to collect and analyse the data, and how all of these enabled answering of the research question (Wyk, 2017). Furthermore, the main emphasis of the research design chapter was to give a proper description of whether the study is qualitative, quantitative or mixed methods. It could also be divided into three categories that is; exploratory, experimental or descriptive depending on the kind of study a researcher is trying to conduct.

This research was basically a Network Problem in nature and it was to incorporate the shortest path approaches of collecting data. A Network Problem can take several forms and this study focused on the shortest path to create a transportation Network (Ragsdale, 2007). This was made up of several arcs which are the various cities in the selected countries and these were connected by the various arcs which represented the roads that are connecting the various cities.

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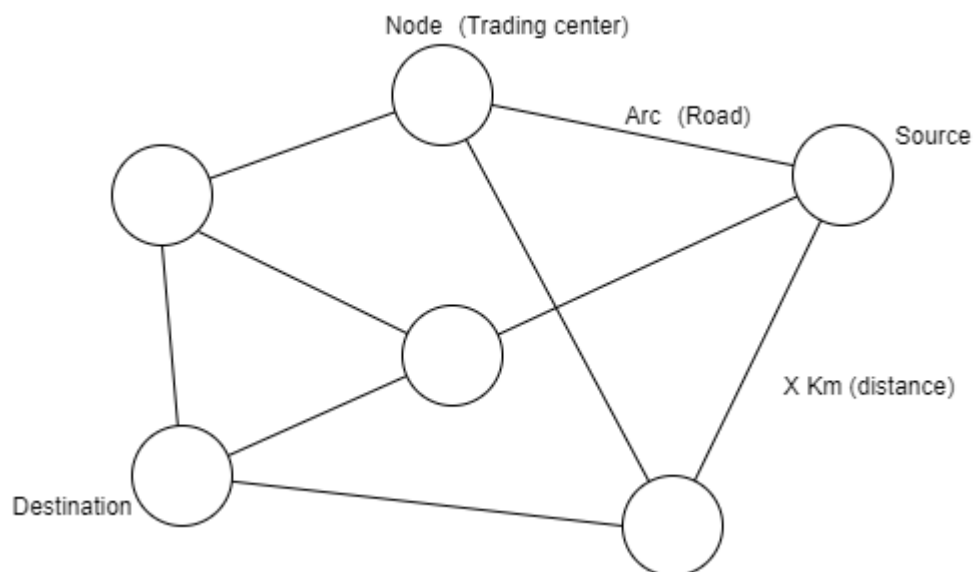


Figure 3.1: Network Representation of Nodes, Arcs, Distances in Km, Destinations and Sources

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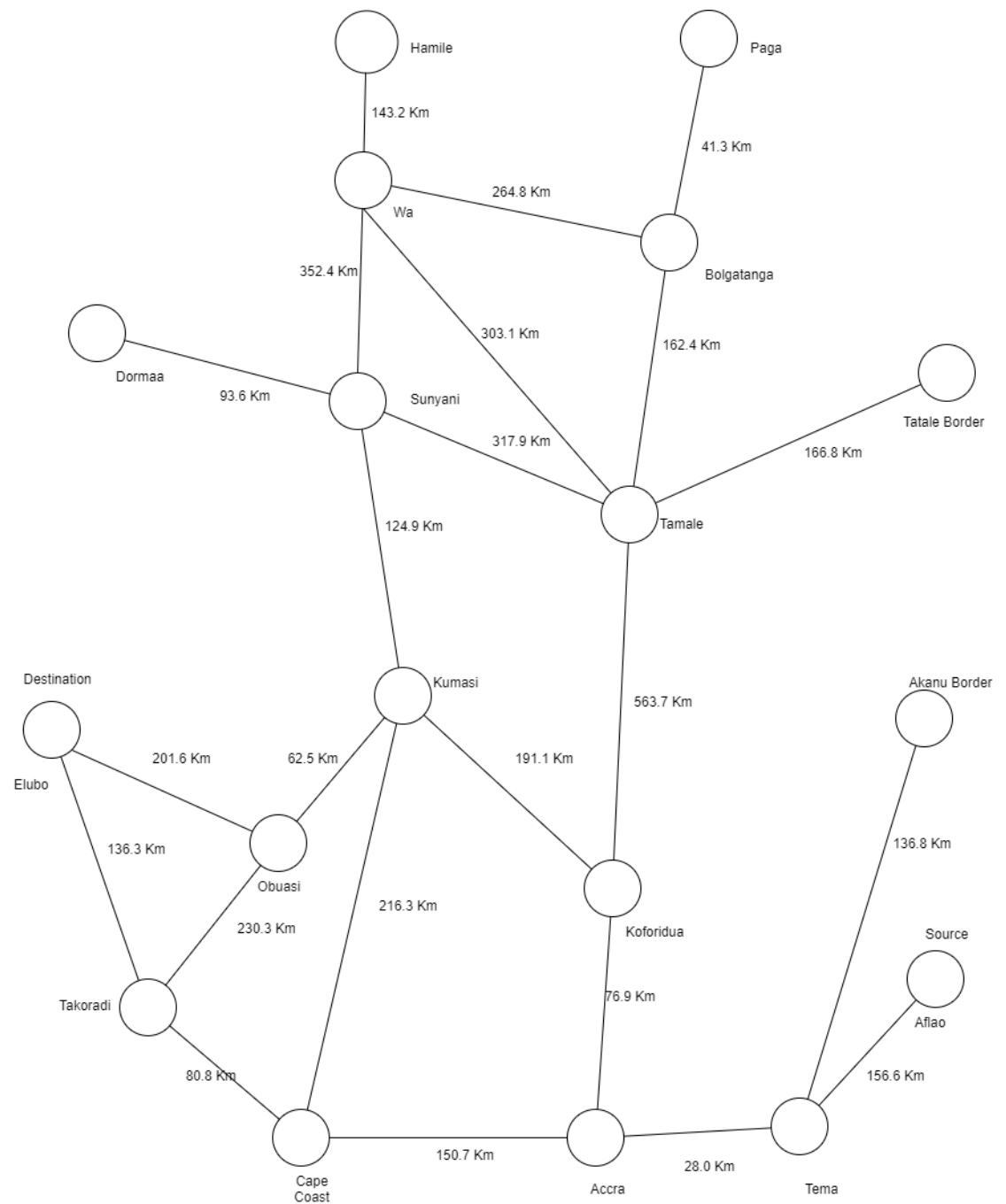


Figure 3.2: Network representation of the route extracted from the Map of Ghana showing Arcs(Cities), Distances in Km, Destinations and Sources (border points).

To add, the quantitative research or approach usually takes the social surveys and experiments for the collection and analysis of its data and so researchers find

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quantitative research more reliable in terms of providing explanations that are adequate at the level of meaning (New York University, 2006).

The study used quantitative data by considering the number of arcs on the model with various lengths which were the distances between the various nodes and the number of nodes which were the cities that were taken as the trade points in the transportation network. All these were geared towards establishing how best the study would come up with the most efficient routes to be used to facilitate the free trade in the region in terms of shortest distance. However, in as much as the measured variables were readily available on Google maps, and would be obtained for analysing to obtain the most efficient routes in terms of distance, its uncertain to just conclude that those are the commonly used routes. Therefore, the thesis is not meant to give a conclusive evidence, hence further research needs to be conducted.

On the other hand, the research instruments used included Google maps where most of the cities and distances between them were obtained, Spreadsheet (solver), Dr Java environment for developing a computer algorithm for the shortest path. The Spreadsheet tool that was used has an advantage to optimization in a way that many optimization models can be represented in an understandable fashion (Thanh-Ha-Nguyen & Meissner, 2017). More still, most of the PCs built today come with built in optimizers and so this research employed the use of the solver optimizer. “The Solver Tool has the capability to solve linear (and often nonlinear) programming” (edx, 2017). Due to its efficiency, it can be used to solve up to 200 decision variables. This is incorporated in the simplex method which is the commonly used method for solving problems that usually involve more than two variables or problems that involve a large number of constraints (Cengage, 2017). Since the study involved the use and analysis

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of the data with the help of the computer software, it was better to use solution methods such as the simplex method that are adaptable to computers.

3.3 Research Scope

3.3.1 Study Population

The study population for this research was about the ECOWAS region and this comprises of approximately fifteen countries, however, because of some limitations in the study such as time, the research focused on only four countries that is; Ghana, Cote D'Ivoire, Burkina Faso and Togo. In the same way, the study made assumptions about selecting ten major cities in each country and these should have trading centres where the small feeder roads would deliver goods from the different producers, ready to be transported to the neighbouring countries for export. Due to the above assumption, the study also narrowed down the number of routes to be considered, this is because there were a number of inter routes in all these countries, but the study focused only on at most 3 roads linking the main 10 trading cities around the various countries.

3.3.2 Study Area

The study area was the four countries of the ECOWAS sub-region, that is Ghana, Togo, Burkina Faso and Cote D'Ivoire. These are countries in West Africa and they boarder each other. The research identified the various 10 major cities in each of these countries and the different road networks in the particular countries and how they were connecting these cities.

3.4 Sampling Strategy

3.4.1 Sampling techniques

The sampling technique used in the study was the Non-Probability sampling technique. Non-probability sampling is used to represent a group of sampling

techniques that help researchers to select units from a population that they are interested in studying (Non-Probabilistic sampling, 2012). These units are used as the study sample by the researcher. In other words, the researcher doesn't select the respondents randomly, but rather on subjective judgement of the researcher.

The Non-Probabilistic sampling technique can take different forms such as Quota sampling, convenience sampling, purposive sampling, self-selection sampling and snowball sampling. The study employed a purposive Non-Probabilistic type of sampling. This provides strategic choices about with whom, where and how the researcher will carry out the research (Palys, 2008).

To add, the research wanted to find out whether the transportation model would be easily formulated for countries that are bordering each other such as Ghana and Togo and then a generalization can be made as to whether it can be formulated for countries that do not share any borders such as Ghana and Nigeria. This sampling technique also played a key role in the selection of which routes to consider in amidst of all the routes that are in the different countries, as well as the cities that were considered as trading centres. These routes were selected due to the Google maps recommendation as being the shortest distances putting into consideration other factors such as traffic.

3.4.2 Sample Sizes

Considering the sub population that was used for the study, a sample size of 4 ECOWAS sub-region countries was used and within these four countries, 10 cities were selected from each country to represent the various trade centres in the various countries. After establishing these sample sizes, at most 3 routes were considered in connecting a city to other cities. Since this was a case study, it could not be deduced that the sample size was representative of the region.

3.5 Data Collection

3.5.1 Data Collection Instrument

The data collected was secondary and this was mainly obtained from google maps by the help of the internet. Due to its secondary nature, it was readily available for extraction from Google maps.

3.5.2 Data Collection Procedure and Method of Analysis

Some prior research was conducted online to determine how easily the data could be extracted from the internet (Google Maps). The researcher determined the sampling method, the sample sizes to use and analysis method. Sampling Methods: Purposive Sampling; Sample size: 4 countries, 10 cities, 3 road networks; Analysis Method: Simplex method; Computer Statistical Software: Spreadsheet; the generation of analysis reports and DrJava for the programming code.

3.5.3 Data Preparation, Collation and Processing

After obtaining data from Google maps, the researcher entered the data into the Spreadsheets where most of it was formulated into decision variables, objective functions and constraints. The decision variables were taken as the figures that kept varying as the data was being analysed in the Spreadsheet. The constraints were the inequality functions formulated using the data and these were usually equated to 1, 0, or -1. This was dependent on whether the particular node for which a constraint was formulated was receiving, not receiving or giving away its content respectively. The Objective function too was created as a function in terms of “Min” since the objective was to minimise the total distance travelled. This was made up of all possible distances that would be considered in establishing an optimal path. When all these three aspects were formulated, they were then processed into meaningful information and then solved

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using the Simplex method, by the help of Solver (an inbuilt optimization software in Microsoft Excel) to obtain the optimal shortest path.

The Data was also coded into the Java programming language using the DrJava environment. This was to ascertain the results that were obtained and to give a more concrete answer by the use of the Dijkstra's algorithm which is known to be the commonly used computer programming algorithm for finding the shortest path.

3.6 Data Analysis

The data collected was fed into Spreadsheet after being formulated into constraints, decision variables and objective function. Thereafter, it was run through solver to determine the optimal path that gave the minimum distance to be covered on the path. Solver is mainly used to solve optimization problems and using its simplex method, it can be used to solve several decision variables. After obtaining an optimal path, there was no sensitivity analysis run for the work because of restrictions in a transportation model. This is mainly because the transport model is not dynamic in a way that distances cannot change as compared to variables like cost or price, hence it wasn't holding for this particular problem.

In order to come up with a very concrete solution, another method was used to obtain an optimal path, and this was the use of the Dijkstra's algorithm which involved writing a programming code to determine a shortest path. This was to help give a deeper analysis of the optimal path obtained by the two approaches as to whether they are similar or different. This code worked in a way that these distances were hard coded into the adjacency matrix of the Dijkstra's algorithm and it was able to generate the array list of the points (cities) that provided the shortest path from the start point to the destination.

3.7 Validity and Reliability

The concept of reliability and validity is very common in quantitative research and now it is reconsidered in the qualitative research too (Golafshani, 2003). These are very relevant in research concepts and they are very crucial reflecting the multiple ways in which the truth can be established from the research being conducted.

Reliability in a research method refers to consistency in a measure. In the quest of embarking on a particular study, researchers usually apply particular measures in conducting research for a particular study and therefore, there needs to be consistency in the measure that the researcher is using in order not to create bias in the study.

The data used in the study was obtained online from a trusted source and that is Google maps. The software uses very high sophisticated technology that is used to determine this data from satellites, and this makes the data obtained for the study valid and reliable.

The study used two methods to obtain the optimal path, that is the use of Spreadsheet which employs the Simplex method and then the Dijkstra's algorithm which was to write a computer programming code. This was to help compare and contrast the various optimal paths obtained to see whether they are similar or different and then deductions can be made basing on the obtained answers.

3.8 Limitations and Delimitations

The study encountered several limitations such as time, assumptions and resources. Time was the greatest limitation because the study had to be conducted in a few months and so this posed a limitation to the number of countries, the cities and the routes to be considered. This is because if the study was to consider all the 15 countries

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in the ECOWAS region, that would lead to generation of a lot of decision variables and constraints which would also require a lot of time to analyse.

Secondly, another factor was the resources, the researcher did not have enough resources such as finances to obtain primary data. Therefore, the study relied mostly on secondary data which was readily available for extraction online from Google Maps and this was in terms of distances between the various points (cities). Some secondary data was also not available which resulted in making of a couple of assumptions in the study which might make the work a bit biased.

In addition, the study made a lot of assumptions and these turned out to be limitations to the study. The study took into consideration some factors and held some other factors constant or negligible and yet they might have an influence on transportation. Take for instance, there were a number of exit points that are located on each country that could have been used in the study, however the study took into consideration a few exit points.

Most of the cities chosen too may not necessarily be trading centres, but the study made assumptions that these 10 cities that were selected in each country are gazetted as major trading centres. Considering the road networks, there are thousands of road networks in each country, but the study noted out only nodes connecting those routes joining the city and are noted to be the most efficient from Google maps putting into consideration factors such as traffic. The study also made assumptions that these selected routes were free of any traffic and they were well constructed which may not necessarily be true.

3.9 Formulation

This subsection focused on how the various decision variables, constraints and Objective function were formulated from the collected data. These were formulated in

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terms of inequalities, for instance the Objective function required addition of the various distances with the variable X . The constraints too were formulated as inequalities that were equated to -1, 0 or 1 depending on whether the node was a source, transit point or destination such as;

3.9.1 Decision variables for the Network

The Network shown in Figure 3.2 shows a graphical representation of one of the Network problems being solved in this study. The Network comprised of the nodes (circles) which represented the various city centres in Ghana and the arcs (arrows) that were connecting the various nodes which represented the various transportation routes that could be used for the transportation of the products. Since the study sought out to find the shortest distance travelled, then the arcs formed the decision variables.

X_{ij} = the distance travelled from one city to another from node i to node j

The model in Figure 3.2 had 18 arcs and so this required formulation of 18 decision variables:

X_{12} = the distance travelled from node 1 (Aflao) to node 2 (Tema)

X_{23} = the distance travelled from node 2 (Tema) to node 3 (Accra)

X_{34} = the distance travelled from node 3 (Accra) to node 4 (Capecoast)

X_{36} = the distance travelled from node 3 (Accra) to node 6 (Kofiridua)

X_{54} = the distance travelled from node 5 (Takoradi) to node 4 (Capecoast)

X_{57} = the distance travelled from node 5 (Takoradi) to node 7 (Obuasi)

$X_{5,13}$ = the distance travelled from node 5 (Takoradi) to node 13 (Elubo)

X_{68} = the distance travelled from node 6 (Kofiridua) to node 8 (Kumasi)

X_{69} = the distance travelled from node 6 (Kofiridua) to node 9 (Tamale)

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$X_{7,13}$ = the distance travelled from node 7 (Obuasi) to node 13 (Elubo)

X_{84} = the distance travelled from node 8 (Kumasi) to node 4 (Capecoast)

X_{87} = the distance travelled from node 8 (Kumasi) to node 7 (Obuasi)

$X_{8,10}$ = the distance travelled from node 8 (Kumasi) to node 10 (Sunyani)

$X_{9,10}$ = the distance travelled from node 9 (Tamale) to node 10 (Sunyani)

$X_{9,12}$ = the distance travelled from node 9 (Tamale) to node 12 (Wa)

$X_{9,11}$ = the distance travelled from node 9 (Tamale) to node 11 (Bolgatanga)

$X_{10,12}$ = the distance travelled from node 10 (Sunyani) to node 12 (Wa)

$X_{12,11}$ = the distance travelled from node 12 (Wa) to node 11 (Bolgatanga)

The decisions variables for the other networks are represented in the Appendix.

3.9.2 Objective function for the Network.

In this network model, movement from one node i to node j involved movement of a certain distance in Kilometers (Km). This distance represented the total distance travelled from one city to another and since the paper was trying to find the shortest path among then, hence a minimum distance network flow problem was created. Therefore, the objective function was given as follows;

Objective function from Aflao to Elubo

$$\begin{aligned} \text{MINIMISE: } & 156.6X_{12} + 28.0X_{23} + 76.9X_{36} + 150.7X_{34} + 563.7X_{69} + 162.4X_{9,11} + \\ & 303.1X_{9,12} + 264.8X_{12,11} + 352.4X_{10,12} + 317.9X_{9,10} + 124.9X_{8,10} + \\ & 191.1X_{68} + 216.3X_{84} + 80.8X_{54} + 230.3X_{57} + 62.5X_{87} + 201.6X_{7,13} + \\ & 136.3X_{5,13} \end{aligned}$$

The term $156.6X_{12}$ in the objective function meant that there was a distance of 156 Km between node 1 (Aflao) to node 2 (Tema). This applies to all the other terms in the

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function and similar objective functions are represented in the Appendix for the other networks.

3.9.3 Constraints of the Network

Just like the decision variables were determined by the number of arcs, constraints were determined by the number of nodes. The model in Figure 3.2 had 13 nodes and so it had 13 constraints. The constraint represented that all the products produced would be moved to the next city until they moved from the source to the destination. These were represented as shown below:

Subject to:

$$\begin{aligned}
 0 - X_{12} &= -1 \text{ flow constraint for node 1} \\
 +X_{12} - X_{23} &= 0 \text{ flow constraint for node 2} \\
 +X_{23} - X_{36} - X_{34} &= 0 \text{ flow constraint for node 3} \\
 +X_{34} - X_{45} - X_{48} &= 0 \text{ flow constraint for node 4} \\
 +X_{45} + X_{57} - X_{5,13} &= 0 \text{ flow constraint for node 5} \\
 +X_{36} - X_{69} - X_{68} &= 0 \text{ flow constraint for node 6} \\
 +X_{87} + X_{7,13} - X_{57} &= 0 \text{ flow constraint for node 7} \\
 +X_{6,8} + X_{8,10} - X_{48} - X_{89} &= 0 \text{ flow constraint for node 8} \\
 +X_{69} - X_{9,11} - X_{9,12} - X_{9,10} &= 0 \text{ flow constraint for node 9} \\
 +X_{10,12} + X_{9,10} - X_{8,10} &= 0 \text{ flow constraint for node 10} \\
 +X_{9,11} - X_{11,12} &= 0 \text{ flow constraint for node 11} \\
 +X_{11,12} + X_{9,12} - X_{10,12} &= 0 \text{ flow constraint for node 12} \\
 +X_{5,13} + X_{7,13} &= 1 \text{ flow constraint for node 13}
 \end{aligned}$$

3.9.4 Implementation

The implementation of the data collected was done by the use of the simplex method in Spreadsheet. This took in the formulated decision variables, objective functions and constraints to give out an optimal path.

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The Dijkstra's algorithm that was coded in DrJava helped determine the optimal path by getting a clear modelling of the shortest path algorithm as opposed to the Simplex method one that was done in the backend. The coded program showed a clear description and logic behind establishing an optimal path.

CHAPTER IV – DATA ANALYSIS AND DISCUSSION

4.1 Introduction

This chapter presents the results and analysis of the networks as represented in Figure 3.2 in the Methodology chapter on page 37. These networks were analysed for the optimal path for transportation of products from one Ecowas country to another especially from one entry point to another exit point and this was done for all the four countries in the sub-region under study. Data that was collected was in terms of the various distances from one vertex (city) to another in a particular country. The methods used to analyse this data were the simplex method and the Dijkstra's algorithm. The Simplex method is noted out as the efficient method for finding the shortest optimal path as stated in the Introduction chapter on page 24. The Dijkstra's algorithm was also used in the analysis of the data to have a better comparison of the results and validity of the answers and further details are described in chapter 2 on page 30.

All the data that was collected and analysed was represented in form of graphs and it was also populated into excel sheets and these are included in the appendix. These findings were analysed in order to answer the research questions and also achieve the research objective that was mentioned in Chapter one. As stated in the methodology chapter, the data used for the analysis was quantitative and this was secondary data that was readily available online for harnessing, retrieving and analysing.

4.2 Optimal path Analysis of the Data using the Simplex method

4.2.1 Setting a Target cell

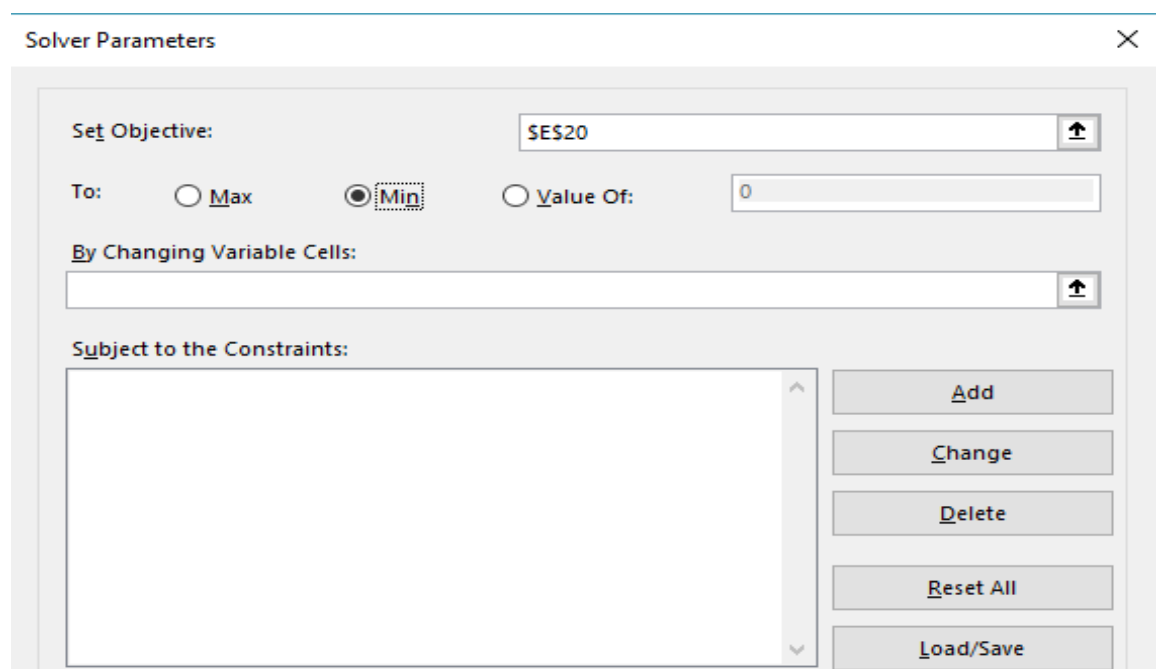
The first step in the solution process was to set a target cell where the optimal distance value of the objective function would be stored. This cell was chosen to be \$E\$20. The objective function as formed on the page 43 of the Methodology chapter

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was coded using the following excel syntax `SUMPRODUCT($I4:$I$17,$G$4:$G$17)`, where the range of cells represented the decision variables.

4.2.2 Setting the Optimality

Since the study was looking for the shortest path or minimal distance that could be covered in the transportation of products from one entry border point to another, a decision was made to use the minimum optimality (MIN) as shown in the *Figure 4.1* below.



The image shows the 'Solver Parameters' dialog box in Microsoft Excel. The 'Set Objective' field is set to '\$E\$20'. Below it, the 'To' section has three radio buttons: 'Max', 'Min', and 'Value Of:'. The 'Min' radio button is selected. The 'Value Of' field is set to '0'. The 'By Changing Variable Cells' field is empty. The 'Subject to the Constraints' section is empty. On the right side, there are buttons for 'Add', 'Change', 'Delete', 'Reset All', and 'Load/Save'.

Figure 4.1: Setting the Target Cell and Optimality

4.2.3 Setting the Variable Cells

The Variable cells represent the cells that contain the decision variables of the model. These decision variables took on different values in a constrained optimization problem. For the start, we assumed that they were at a zero level. This was just a start point for the simplex algorithm. The range of cells `I6:I22` was designated to contain the values of the decision variables at optimality as shown in Figure 4.2.

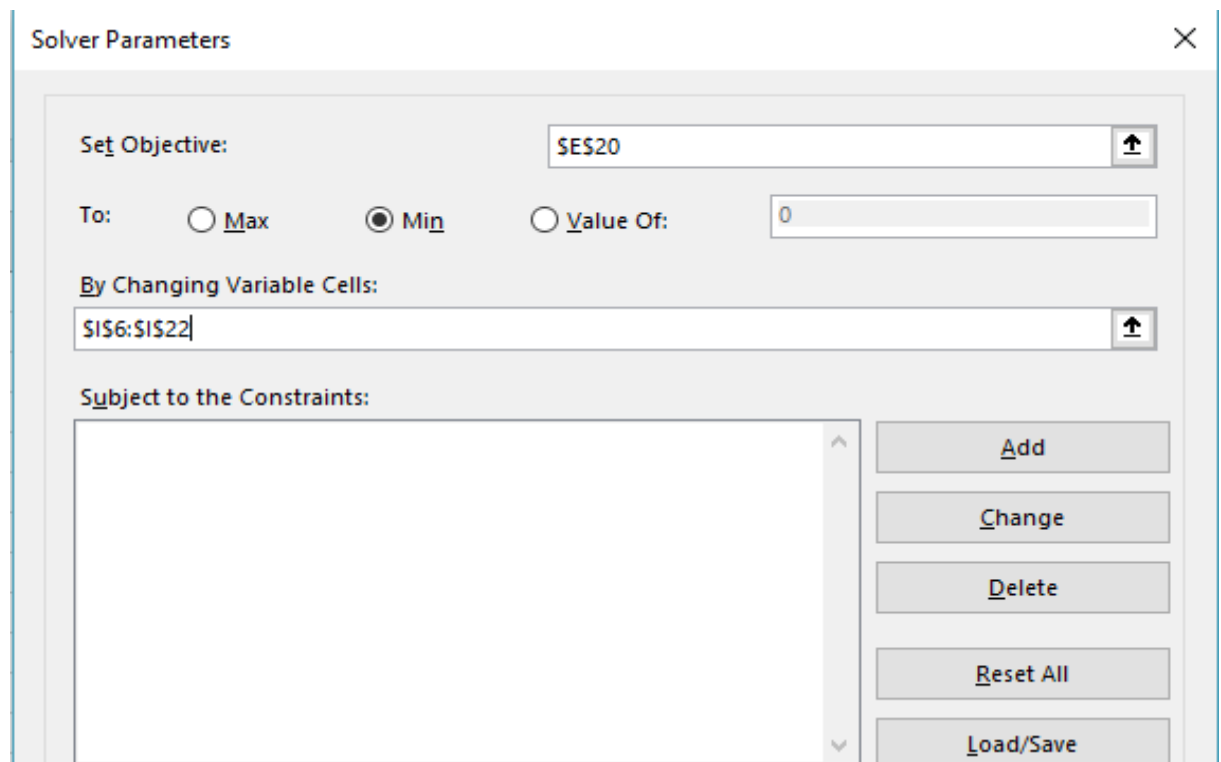


Figure 4.2. Setting the Changing variable cells

4.2.4 Setting the Constraints Cells

Since the problem was a constrained optimization problem, we needed to code the constraints in the model () on page 45. Recall that the constraint had a left and right-hand side expressions with equality of both sides. This equality of both sides was due to the fact that the Netflow of the goods had to be equal to the supply or demand because an assumption was made that everything that was transited from one entry point had to be passed on to another point until it reached the exit point. The syntax used for the right hand side was $\$M\$3:\$M\10 and that of the left-hand side was $=\$N3\$N10$ and these eventually had to be equated as shown in the following syntax; $M\$3:\$M\$10=\$N3\$N10$. In order to implement the Netflow constraint cells in the excel sheet, the following syntax was used $(=SUMIF(\$E\$5:\$E\$20,K5,\$I\$5:\$I\$20)-$

SUMIF(\$C\$5:\$C\$20,K5,\$I\$5:\$I\$20)) and this was repeated for all the other cells that formed part of the constraint cells.

The image shows the 'Solver Parameters' dialog box. The 'Set Objective' field contains '\$E\$20'. Below it, the 'To' section has three radio buttons: 'Max', 'Min' (which is selected), and 'Value Of:'. The 'Value Of' field contains '0'. The 'By Changing Variable Cells' field contains '\$I\$6:\$I\$22'. The 'Subject to the Constraints' list contains '\$M\$3:\$M\$10 = \$N\$3:\$N\$10'. To the right of this list are five buttons: 'Add', 'Change', 'Delete', 'Reset All', and 'Load/Save'.

Figure 4.3. Setting the cells subject to Constraints

4.2.5 Setting the Non-negativity conditions

Since the measurements involved distances, it was proper to assume them non-negative this is simply because there are no negative distances. Therefore, we imposed a non-negativity constraint on the decision variables in the models. The following syntax was an expression of the non-negativity constraints; $\$I\$6:\$I\$22 \geq 0$. The process was repeated for all the other routes on the various networks. This is shown in Figure 4.4 below.

Solver Parameters ✕

Set Objective: ↑

To: ☐ Max ☒ Min ☐ Value Of:

By Changing Variable Cells: ↑

Subject to the Constraints:

\$I\$6:\$I\$22 >= 0

\$M\$3:\$M\$10 = \$N\$3:\$N\$10

Add

Change

Delete

Reset All

Load/Save

Figure 4.4. Setting the Non-negativity Constraints

4.2.6 Simplex Method

The study chose the simplex Method to solve the transportation problem due its comparative advantages as discussed in chapter two on page 24. In solver we needed to indicate this by selecting among the various methods and the Simplex LP option was selected as shown in Figure 4.5 below. This concluded the setting up stage in the solution process. In what followed, we solved the Lp model to obtain the optimum distance and the corresponding decision values.

Solver Parameters

Set Objective:

To: ☐ Max ☒ Min ☐ Value Of:

By Changing Variable Cells:

Subject to the Constraints:

☒ Make Unconstrained Variables Non-Negative

Select a Solving Method:

Solving Method

Select the GRG Nonlinear engine for Solver Problems that are smooth nonlinear. Select the LP Simplex engine for linear Solver Problems, and select the Evolutionary engine for Solver problems that are non-smooth.

Buttons: Add, Change, Delete, Reset All, Load/Save, Options, Help, Solve, Close

Figure 4.5. Setting the Solving method

4.2.7 Solving the Model

After implementing all the above procedures, the numbers that appeared in the variable cells represented the various towns or routes that formed part of the shortest path solution as shown in *Figure 4.6*. These were contained in a range of cells I5:I17 as zeros and ones, where ones represented the routes that were part of the optimal solution/ path and zeros represented routes/paths that were not included in the optimal path. A minimum distance of 446.8 Km as shown in the cell G20 in *Figure 4.6* was

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generated representing the shortest distance that needed to be covered from the start point to the endpoint that is from Ketao to Aflao. Similar optimal paths were found for the other network models under consideration as shown in the Appendix.

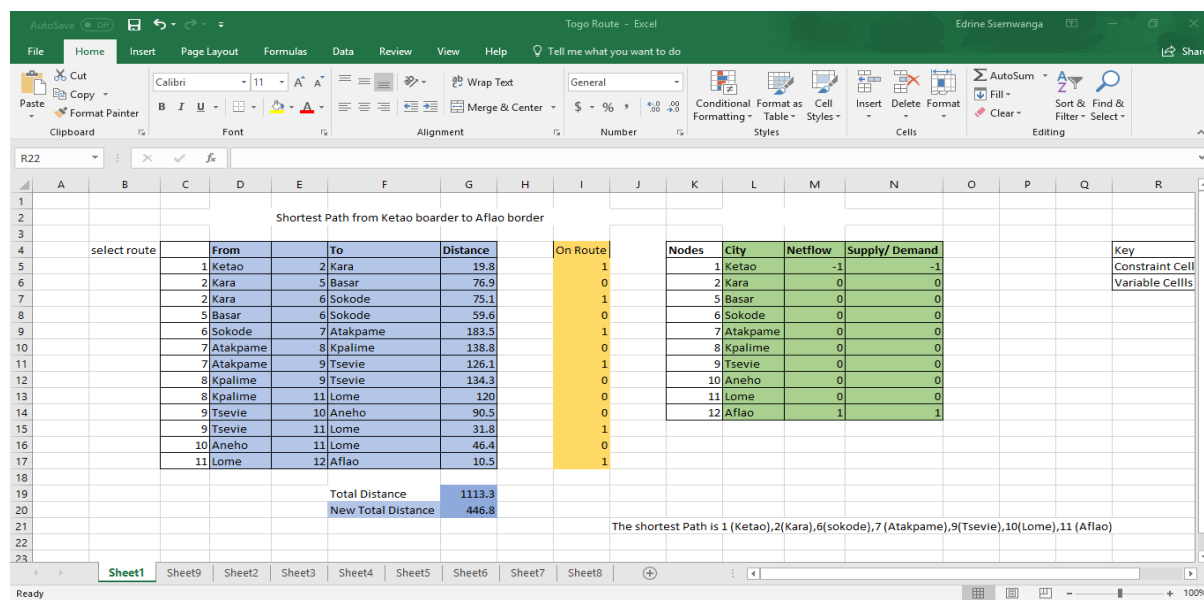


Figure 4.6: Solving the Model

4.3 Analysing the solution

4.3.1 Analysis of the Solver solution

Analysis of the solution that was represented in Figure 4.6 sought to identify the various points that is, the towns or cities in the various countries under study and the routes which are the representation of the roads on the map that were traced out in the shortest path. The range of cells I4:I17 (On Route cell) were populated by ones and zeros and these represented the optimal and non-optimal cells respectively. The analysis was conducted for individuals network models to determine the shortest path for each of them take for instance;

Shortest Path from Ketao to Aflao: Ketao > Kara > Sokode > Atakpame > Tsevie > Lome > Aflao.

Shortest Path from Aflao to Elubo: Aflao > Tema > Accra > Capecoast > Takoradi > Elubo

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Shortest path from Aflao to Dormaa: Aflao > Tema > Accra > Kofiridua > Kumasi > Sunyani > Dormaa

Shortest path from Aflao to Hamile: Aflao > Tema > Accra > Kofiridua > Kumasi > Sunyani > Hamile

Shortest path from Elubo to Kaouara: Elubo > Abidjan > Divo > Yamousskro > Bouake > Korhogo > Kaouara

Shortest path from Elubo to Pogo: Elubo > Abidjan > Divo > Yamousskro > Bouake > Korhogo > Pogo

Shortest path from Dormaa to Kaouara: Dormaa > Yamoussoukro > Bouake > Korhogo > Kaouara

Shortest path from Ketao to Akanu: Ketao > Kara > Sokode > Atakpame > Kpalime > Akanu

This implied that in as much as all these routes were on the network, after doing a proper analysis of the various distances between the various cities, the above were some of the optimal points in the objective function that could be considered in the movement across the sub-region. That is what brought to the conclusion of not having all the cities in the network as part of the optimal but a few cities. Since the method was designed to find an optimal path, it compared all the various distances and then traced out the routes that would provide the shortest distance from the start point to the endpoint. As shown from the Figure 4.6, the total distance was 1113.3 Km and the optimal distance was 446.8Km and this was determined to be the shortest distance from the start point of Ketao to the exit point of Aflao.

This representation was done for all the other routes that were being considered in the study as represented in the appendix. The whole analysis sought to bring to the reader's understanding that there was a need to identify particular towns or cities which need to be connected together by roads in order to reduce the total distance that had to be travelled while transporting goods around the sub-region. Hence, enhancing the free trade in the region by promoting easy and fast transportation of the products around the ECOWAS sub-region.

4.4 Dijkstra's Algorithm

4.4.1 Analysis of the Dijkstra's Algorithm code

An alternative means was used to find the shortest path and that was the use of the Dijkstra's algorithm. This generated the same answers as the Simplex method and it was more flexible than the Simplex method as it could generate answers from every point in the network as opposed to the Simplex method that focused more on the distance from entry point to the last point.

The code took on an assumption of a graph, a destination, some source vertices in the graph and then a shortest path was created from the source to all vertices in the given graph. Since the graph was not a negative weights graph, that is to say edges with negative values therefore, the Dijkstra's algorithm was another better option for analysing our data as it was designed not to work for graphs with negative weight edges.

Therefore, a Shortest Path Tree (SPT) was generated with a given source as root and this was the entry point from a particular country such as Aflao from Ghana or Ketao in Togo. While running the code, two sets were generated, that is one having the points that are in the SPT, and the other vertices that are not in the SPT. This was implemented by observing a number of steps that were followed to determine the shortest path that was generated by the algorithm of the code which is represented in the appendix.

4.4.2 Steps for finding shortest path

The first step was to set the Shortest Path Tree set (sptSet) that kept track of vertices or points that were included in the shortest path tree. Before the code was run, this set was initially empty and after running it points with minimum distance from source were to be calculated and finalized.

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The second step was to assign values in terms of distances to all vertices or points in the input graph. All these values were initialized as infinite due to the uncertainty of what would be their final shortest distance from the source. Then the source vertex or point was assigned a distance value as zero so that it was picked first.

The third step noted that, since the `sptSet` was still empty without any points, a particular vertex `u` was picked that had a minimum distance value from the source as compared to the other vertices, but it was not in the `sptSet` yet. This value was then included into the `sptSet` as the first value. An update of the distance value was made to all adjacent vertices of the selected vertex `u`. Therefore, an algorithm was implemented that updated the distance values by iterating through all adjacent vertices.

Fourthly, “For every adjacent vertex `v`, if the sum of the distance value of vertex `u`, that is from the source and weight of edge `u-v`, is less than the distance value of `v`, then update the distance value of `v`” (Greek). Forexample from Ketao to Aflao, the source was Ketao and the adjacent vertex `u` with the smallest distance would be the nearest city or town. A Boolean array `sptSet[]` which takes “true” or “false” as parameters was used to represent the set of vertices that were included in the SPT. Once a value `sptSet[v]` was true, then that particular vertex `v` was included in SPT, otherwise not and this was made to run through a loop until all the vertices were looped through. Another array called `dist[]` was created which was used to store the shortest distance values of all vertices and later displayed them when the code was run.

A parent array was also created which indicated that before moving to a particular vertex, we might have come from a certain vertex, and so this was the array that held such values. Then, an update was made on the parent array when the distance was updated and used it to show the shortest path from source to different vertices.

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Finally, an adjacency matrix was created which was also used to hard code the values of the distances in the code. The adjacency matrix, is sometimes also called the connection matrix, and this is usually used for simple labelled graphs with rows and columns labelled by graph vertices, with a one or zero in position (v_i, v_j) according to whether v_i and v_j are adjacent or not. This was illustrated in the code by replacing the ones with the distance between the cities and zeros for points that are not adjacent to each other as shown in the Figure 4.7 below and more code snippets are in the Appendix.

```

164 System.out.println("Enter an Entry city Number");
165 int EntName= Integer.parseInt(sc.next().toLowerCase());
166 System.out.println("Enter an Exit city Number");
167 int ExiName= Integer.parseInt(sc.next().toLowerCase());
168 String entIndex = majorCities.get(new Integer(EntName));
169 String exitIndex = majorCities.get(new Integer(ExiName));
170
171 /* Let us create the example graph discussed above */
172 double graph[][] = new double[][]{
173     {0, 19.8, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0},
174     {0, 0, 0, 0, 76.9, 75.1, 0, 0, 0, 0, 0, 0},
175     {0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0},
176     {0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0},
177     {0, 76.9, 0, 0, 0, 59.6, 0, 0, 0, 0, 0, 0},
178     {0, 75.1, 0, 0, 59.6, 0, 183.5, 0, 0, 0, 0, 0},
179     {0, 0, 0, 0, 0, 183.5, 0, 138.8, 126.1, 0, 0, 0},
180     {0, 0, 0, 0, 0, 0, 138.8, 0, 134.3, 0, 120.0, 0},
181     {0, 0, 0, 0, 0, 0, 126.1, 134.3, 0, 90.5, 31.8, 0},
182     {0, 0, 0, 0, 0, 0, 0, 90.5, 0, 46.4, 0, 0},
183     {0, 0, 0, 0, 0, 0, 0, 31.8, 46.4, 0, 10.5},
184     {0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0},
185 };

```

Figure 4.7: Adjacency Matrix with hard coded distances of the various Cities/Towns

4.4.3 Results of the Code

The code calculated the shortest distance, the path information and returned the distances and the shortest path in terms of an array list of the city names. The code found the shortest distances from the source to all the other vertices. Depending on what was supposed to be executed, the code was written in a way that, if the interest was only on the shortest distance from the source to a single target vertex, then the code could be

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broken in the “for loop” as soon as the picked minimum distance vertex was equal to the target and that would be included in the sptSet.

When the code was compiled and ran, because of its java.util package, it had an inbuilt scanner that enabled the user to provide input that was read from the keyboard and then used to give an output. It generated the scanner functionality of giving the user the option to enter a number corresponding to a particular city that is an entry point or exit point depending on the user’s preference on the network. For user friendliness purposes, the code generated the cities and the corresponding numbers that needed to be fed into the system to generate the output. More still, the input entered by the user had to be part of the given cities or points that are on the network because these were hard coded in the code as shown in the snippet of the code in Figure 4.8

After these two inputs were entered correctly, then the code generated the vertex involved in the network and the corresponding calculated distances from the source to that particular vertex. That is to say, “Vertex” on the left and “Distance from source” on the right and then an array list was provided showing the vertices that qualify to be part of the optimal path, which were further reverted back into real city names that were hard coded in the code as shown in the Figure 4.8 below.

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```

3 = divo
4 = yamoussoukro
5 = gagnoa
6 = san-pedro
7 = daloa
8 = duekoue
9 = man
10 = bouake
11 = korhogo
12 = pogo
Enter an Entry city Number
0
Enter an Exit city Number
12
Vertex Distance from Source
0 0.0
1 176.5
2 176.8
3 361.5
4 555.5
5 446.7
6 677.2
7 692.9
8 798.9
9 884.1999999999999
10 661.6
11 890.0
12 1021.1
[0, 1, 3, 4, 10, 11, 12]
elubo > abidjan > divo > yamoussoukro > bouake > korhogo > pogo >
>

```

Figure 4.8. Screen Shot of the Code output

CHAPTER V: CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

In this chapter we summarized the findings from the study and drew conclusions regarding the research problem. We also made some recommendations to stake holders to further research in this area.

5.1.1 Summary

This research sought to tackle the road transportation problem in the ECOWAS sub-region that is comprising of four countries that is Ghana, Togo, Ivory Coast and Burkina Faso. Research in Chapter one revealed that there were quite a number of reasons affecting the free trade in the region such as the poor infrastructure of the roads, tariffs and boarder issues and these caused delays, and high costs involved in the movement of persons and goods across the region. These delays and unreliable costs discouraged the regional free trade as they resulted into an increase in the cost of doing business in West Africa

However, the study made a couple of assumptions that all the other factors affecting transportation are constant, in other words, there are no restrictions on the border points of the various countries, the roads are in good condition that is well tarmacked and have no traffic whatsoever. Secondly, that there were products in each of the country that were of high demand in another country or countries and so these needed to be transported there instead of importing from Western countries.

The study employed two methods that is the Simplex method and Dijkstra's algorithm to work on the problem of delays in the transportation of goods across the region, something that affects the free trade. This is because as goods take long to be delivered, then this has several related challenges such as wastage of perishable goods,

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creation of shortages at the demand points hence resulting in increase in prices that would discourage the local consumers. Therefore, the study sought to trace out routes (roads) that could be used to provide the shortest path on the various networks developed for transporting the products, hence facilitating the free trade.

5.2 Conclusions

There are a number of routes and border points that businesses in the four countries can use to transport their products around the sub-region in order to facilitate the free trade that was introduced by ECOWAS. According to the selected boarder points in the study, it identified a couple of routes that could be used to cover the shortest distance from transporting products across the region in the various countries; take for instance, in Togo, goods entering Togo from Nigeria using the Ketao border can be transported from Ketao to kara town, then they move to Sokode town, then Atakpame town, Tsevie town, Lome town and then finally reach Aflao border that is the border between Togo and Ghana. This route totalled up to a distance of 446.8 Km as compared to the total distance of 1,113.3Km that would have been travelled if the truck had to travel to all the various cities/towns on the network as shown from *Figure 4.7* in chapter 4 on page 53. More shortest paths were established for the other countries as showed in Chapter 4 on page 50. Since Burkina Faso borders all the other 3 countries in their northern parts, this made it easy for it to connect into the shortest path flowing through the sub-region from Nigeria-Togo boarder to Cote D'Ivoire.

According to the Literature review, it was noted out that there are number of transportation challenges that are affecting the free trade as stated in chapter 2 under the Economic implication of transport networks to Economic development of a country sub-chapter. This was to give an understanding that any business that seeks to make profits ought to put into consideration the costs of their operations because they reflect

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on the prices of the products and so one of the ways that a business can reduce its transportation cost by establishing the shortest path from the source of production to the market centre. This is basically what the study was targeting, to find the shortest path from the network to transport the products around the sub-region.

The study was able to come up with the most efficient road transport models in terms of shortest distance that could be used in decision making in terms of transportation to facilitate the free trade in the sub-region as shown in the network models in the appendix. The main objective of this transportation model was to enhance decision making by the various traders that would require transporting their products from the various countries. It would also enable the ECOWAS to get to know how best they can improve the transport infrastructure as well as enforcing the various terms that were discussed in the 1993 treaty among the ECOWAS countries. This is because in as much as the study takes on assumptions of certain road factors being constant or in place, if they are not in place, then the trade will still stay low and ineffective in the region.

On the other hand, the study sought to come up with an algorithm that could be used to determine the most efficient routes in terms of shortest distance. This required coming up with a programming algorithm to help determine the shortest distance from the network model. According to the research, the study discovered that there are a number of algorithms that had been built or used to determine the most efficient paths in terms of shortest distance such as the Dijkstra's algorithm which was used in the study. However, the study modified this algorithm to best fit its needs and came up with a solution for determining the shortest path in the sub region.

5.3 Recommendations

The following recommendations were given to further research in the topic of study and informing policy in order to improve the factors affecting the ECOWAS free trade.

1. The Governments of the various countries under the ECOWAS should come together to effectively implement the ECOWAS treaty policies and removal of any tariffs that are imposed on the goods being imported or exported in their countries. This is because this has been one of the major limitations to this free trade as it causes delays at the boarder points and yet the model relies on good policies that can be used to back the free trade.
2. The study put a couple of assumptions into consideration such as the roads being in undamaged shape, that is well tarmacked and having easy vehicular movement, yet these may not necessarily be the case on ground. Therefore, in order to make the developed transportation model effective, the governments of the various countries have to come together to improve the infrastructure of the existing roads.
3. Due to a number of limitations such as time, the research did not cover all the entire fifteen countries, but only focused on four countries that is Ghana, Togo, cote D'Ivoire and Burkina Faso. Therefore, I would recommend that further study can be made on the topic to study the other remaining twelve ECOWAS countries.
4. The study formulated a java code using the Dijkstra's algorithm that was used to determine the shortest distance from the various points in the network. The study recommends that anyone who wishes to continue with the research would

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look into using another algorithm to determine whether they would get the same optimal path with the used algorithms. Some additions can also be made to the existing code to automate the input and output without having to hardcode the distances in the code as this limits the scope of the code. This can also be used to develop a better Mobile or web App that can be used by the Haulage companies during transportation across the region.

5. A further study could be conducted about the topic but putting into consideration the other forms of transportation such as railway transport. This is because in as much this study tried to determine the most efficient road transportation routes in terms of distance, but a route being short does not necessarily mean being cost effective in terms of low cost. That is why a recommendation is made for further study into the topic with other means of transportation that could make the free trade better.

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APPENDIX

Using the balance-of-flow rule, the LP model to minimize the distance covered from one point (Ketao) to another exit point (Aflao) in this problem is represented.

Objective Functions for Togo routes

From Ketao to Aflao Border exit point.

$$\text{MIN: } 19.8X_{12} + 76.9X_{25} + 75.1X_{26} + 59.6X_{56} + 183.5X_{67} + 138.8X_{78} + 126.1X_{79} + 134.3X_{89} + 120.0X_{8,11} + 90.5X_{9,10} + 31.8X_{9,11} + 46.4X_{10,11} + 10.5X_{11,12}$$

Decision Variables

X_{12} = the distance travelled from node 1(Ketao) to node 2 (Kara)

X_{25} = the distance travelled from node 2(Kara) to node 5 (Basar)

X_{26} = the distance travelled from node 2(Kara) to node 6 (Sokode)

X_{56} = the distance travelled from node 5 (Basar) to node 6 (Sokode)

X_{67} = the distance travelled from node 6 (Sokode) to node 7 (Atakpame)

X_{78} = the distance travelled from node 7(Atakpame) to node 8 (Kpalime)

X_{79} = the distance travelled from node 7(Atakpame) to node 9 (Tsevie)

X_{89} = the distance travelled from node 8(Kpalime) to node 9 (Tsevie)

$X_{8,11}$ = the distance travelled from node 8(Kpalime) to node 11 (Lome)

$X_{9,10}$ = the distance travelled from node 9(Ketao) to node 10 (Aneho)

$X_{9,11}$ = the distance travelled from node 9(Ketao) to node 11 (Lome)

$X_{10,11}$ = the distance travelled from node 10(Aneho) to node 11 (Lome)

$X_{11,12}$ = the distance travelled from node 11(Lome) to node 12 (Aflao)

Subject to:

$$0 - X_{12} = -1 \text{ flow constraint for node 1}$$

$$+X_{12} - X_{25} - X_{26} = 0 \text{ flow constraint for node 2}$$

$$+X_{25} - X_{56} = 0 \text{ flow constraint for node 5}$$

$$+X_{26} - X_{56} - X_{67} = 0 \text{ flow constraint for node 6}$$

$$+X_{67} - X_{78} - X_{79} = 0 \text{ flow constraint for node 7}$$

$$+X_{78} - X_{89} - X_{8,11} = 0 \text{ flow constraint for node 8}$$

$$+X_{89} + X_{79} - X_{9,11} - X_{9,10} = 0 \text{ flow constraint for node 9}$$

$$+X_{9,10} - X_{10,11} = 0 \text{ flow constraint for node 10}$$

$$+X_{9,11} + X_{10,11} - X_{11,12} = 0 \text{ flow constraint for node 11}$$

$$X_{11,12} = 1 \text{ flow constraint for node 12}$$

Road Transportation Model to Facilitate the ECOWAS Free Trade

From Ketao to Akanu Border exit point.

$$\text{MIN: } 19.8X_{12} + 76.9X_{25} + 75.1X_{26} + 59.6X_{56} + 183.5X_{67} + 138.8X_{78} + 126.1X_{79} + 134.3X_{89} + 120.0X_{8,11} + 90.5X_{9,10} + 31.8X_{9,11} + 46.4X_{10,11} + 30.0X_{11,12} + 93.9X_{8,12}$$

Decision Variables

X_{12} = the distance travelled from node 1(Ketao) to node 2 (Kara)

X_{25} = the distance travelled from node 2(Kara) to node 5 (Basar)

X_{26} = the distance travelled from node 2(Kara) to node 6 (Sokode)

X_{56} = the distance travelled from node 5 (Basar) to node 6 (Sokode)

X_{67} = the distance travelled from node 6 (Sokode) to node 7 (Atakpame)

X_{78} = the distance travelled from node 7(Atakpame) to node 8 (Kpalime)

X_{79} = the distance travelled from node 7(Atakpame) to node 9 (Tsevie)

X_{89} = the distance travelled from node 8(Kpalime) to node 9 (Tsevie)

$X_{8,11}$ = the distance travelled from node 8(Kpalime) to node 11 (Lome)

$X_{8,12}$ = the distance travelled from node 8(Lome) to node 12 (Akanu)

$X_{9,10}$ = the distance travelled from node 9(Ketao) to node 10 (Aneho)

$X_{9,11}$ = the distance travelled from node 9(Ketao) to node 11 (Lome)

$X_{10,11}$ = the distance travelled from node 10(Aneho) to node 11 (Lome)

$X_{11,12}$ = the distance travelled from node 11(Lome) to node 12 (Akanu)

Subject to:

$$0 - X_{12} = -1 \text{ flow constraint for node 1}$$

$$+X_{12} - X_{25} - X_{26} = 0 \text{ flow constraint for node 2}$$

$$+X_{25} - X_{56} = 0 \text{ flow constraint for node 5}$$

$$+X_{26} - X_{56} - X_{67} = 0 \text{ flow constraint for node 6}$$

$$+X_{67} - X_{78} - X_{79} = 0 \text{ flow constraint for node 7}$$

$$+X_{78} - X_{89} - X_{8,11} - X_{8,12} = 0 \text{ flow constraint for node 8}$$

$$+X_{89} + X_{79} - X_{9,11} - X_{9,10} = 0 \text{ flow constraint for node 9}$$

$$+X_{9,10} - X_{10,11} = 0 \text{ flow constraint for node 10}$$

$$+X_{9,11} + X_{10,11} - X_{11,12} = 0 \text{ flow constraint for node 11}$$

$$X_{11,12} + X_{8,12} = 1 \text{ flow constraint for node 12}$$

Objective Functions for Ghana routes

From Aflao to Dormaa Border exit point.

Objectivity function from Aflao to Dormaa boarder

Road Transportation Model to Facilitate the ECOWAS Free Trade

$$\begin{aligned} \text{MIN: } & 156.6X_{12} + 28.0X_{23} + 76.9X_{36} + 150.7X_{34} + 563.7X_{69} + 162.4X_{9,11} + 303.1X_{9,12} \\ & + 264.8X_{12,11} + 352.4X_{10,12} + 317.9X_{9,10} + 124.9X_{8,10} + 191.1X_{68} + 216.3X_{84} + 80.8X_{54} \\ & + 230.3X_{57} + 62.5X_{87} + 93.6X_{10,13} \end{aligned}$$

Decision Variables

X_{12} = the distance travelled from node 1 (Aflao) to node 2 (Tema)

X_{23} = the distance travelled from node 2 (Tema) to node 3 (Accra)

X_{34} = the distance travelled from node 3 (Accra) to node 4 (Capecoast)

X_{36} = the distance travelled from node 3 (Accra) to node 6 (Kofiridua)

X_{54} = the distance travelled from node 5 (Takoradi) to node 4 (Capecoast)

X_{57} = the distance travelled from node 5 (Takoradi) to node 7 (Obuasi)

X_{68} = the distance travelled from node 6 (Kofiridua) to node 8 (Kumasi)

X_{69} = the distance travelled from node 6 (Kofiridua) to node 9 (Tamale)

X_{84} = the distance travelled from node 8 (Kumasi) to node 4 (Capecoast)

X_{87} = the distance travelled from node 8 (Kumasi) to node 7 (Obuasi)

$X_{8,10}$ = the distance travelled from node 8 (Kumasi) to node 10 (Sunyani)

$X_{9,10}$ = the distance travelled from node 9 (Tamale) to node 10 (Sunyani)

$X_{9,12}$ = the distance travelled from node 9 (Tamale) to node 12 (Wa)

$X_{9,11}$ = the distance travelled from node 9 (Tamale) to node 11 (Bolgatanga)

$X_{10,12}$ = the distance travelled from node 10 (Sunyani) to node 12 (Wa)

$X_{10,13}$ = the distance travelled from node 10 (Sunyani) to node 13 (Dormaa)

$X_{12,11}$ = the distance travelled from node 12 (Wa) to node 11 (Bolgatanga)

Subject to:

$$0 - X_{12} = -1 \text{ flow constraint for node 1}$$

$$+X_{12} - X_{23} = 0 \text{ flow constraint for node 2}$$

$$+X_{23} - X_{36} - X_{34} = 0 \text{ flow constraint for node 3}$$

$$+X_{34} - X_{45} - X_{48} = 0 \text{ flow constraint for node 4}$$

$$+X_{36} - X_{69} - X_{68} = 0 \text{ flow constraint for node 6}$$

$$+X_{69} - X_{9,11} - X_{9,12} - X_{9,10} = 0 \text{ flow constraint for node 9}$$

$$+X_{9,11} - X_{11,12} = 0 \text{ flow constraint for node 11}$$

$$+X_{11,12} + X_{9,12} - X_{10,12} = 0 \text{ flow constraint for node 12}$$

$$+X_{10,12} + X_{9,10} + X_{8,10} - X_{10,13} = 0 \text{ flow constraint for node 10}$$

$$+X_{6,8} + X_{84} + X_{78} - X_{8,10} = 0 \text{ flow constraint for node 8}$$

$$+X_{57} - X_{87} = 0 \text{ flow constraint for node 7}$$

$$+X_{57} - X_{45} = 0 \text{ flow constraint for node 5}$$

$$X_{10,13} = 1 \text{ flow constraint for node 13}$$

From Aflao to Hamile Border exit point.**Objectivity function from Aflao to Hamile boarder**

$$\text{MINI: } 156.6X_{12} + 28.0X_{23} + 76.9X_{36} + 150.7X_{34} + 563.7X_{69} + 162.4X_{9,11} + 303.1X_{9,12} \\ + 264.8X_{12,11} + 352.4X_{10,12} + 317.9X_{9,10} + 124.9X_{8,10} + 191.1X_{68} + \\ 216.3X_{84} + 80.8X_{54} + 230.3X_{57} + 62.5X_{87} + 143.2X_{12,13}$$

Decision Variables

X_{12} = the distance travelled from node 1(Aflao) to node 2 (Tema)

X_{23} = the distance travelled from node 2 (Tema) to node 3 (Accra)

X_{34} = the distance travelled from node 3 (Accra) to node 4 (Capecoast)

X_{36} = the distance travelled from node 3 (Accra) to node 6 (Kofiridua)

X_{54} = the distance travelled from node 5 (Takoradi) to node 4 (Capecoast)

X_{57} = the distance travelled from node 5 (Takoradi) to node 7 (Obuasi)

X_{68} = the distance travelled from node 6 (Kofiridua) to node 8 (Kumasi)

X_{69} = the distance travelled from node 6 (Kofiridua) to node 9 (Tamale)

X_{84} = the distance travelled from node 8 (Kumasi) to node 4 (Capecoast)

X_{87} = the distance travelled from node 8 (Kumasi) to node 7 (Obuasi)

$X_{8,10}$ = the distance travelled from node 8 (Kumasi) to node 10 (Sunyani)

$X_{9,10}$ = the distance travelled from node 9 (Tamale) to node 10 (Sunyani)

$X_{9,12}$ = the distance travelled from node 9 (Tamale) to node 12 (Wa)

$X_{9,11}$ = the distance travelled from node 9 (Tamale) to node 11 (Bolgatanga)

$X_{10,12}$ = the distance travelled from node 10 (Sunyani) to node 12 (Wa)

$X_{12,11}$ = the distance travelled from node 12 (Wa) to node 11 (Bolgatanga)

$X_{12,13}$ = the distance travelled from node 12 (Wa) to node 13 (Hamile)

Subject to:

$$0 - X_{12} = -1 \text{ flow constraint for node 1}$$

$$+X_{12} - X_{23} = 0 \text{ flow constraint for node 2}$$

$$+X_{23} - X_{36} - X_{34} = 0 \text{ flow constraint for node 3}$$

$$+X_{34} - X_{45} - X_{48} = 0 \text{ flow constraint for node 4}$$

$$+X_{36} - X_{69} - X_{68} = 0 \text{ flow constraint for node 6}$$

$$+X_{69} - X_{9,11} - X_{9,12} - X_{9,10} = 0 \text{ flow constraint for node 9}$$

$$+X_{9,11} - X_{11,12} = 0 \text{ flow constraint for node 11}$$

$$+X_{8,10} + X_{9,10} - X_{10,12} = 0 \text{ flow constraint for node 10}$$

$$+X_{6,8} + X_{84} + X_{78} - X_{8,10} = 0 \text{ flow constraint for node 8}$$

$$+X_{57} - X_{87} = 0 \text{ flow constraint for node 7}$$

$$+X_{57} - X_{45} = 0 \text{ flow constraint for node 5}$$

Road Transportation Model to Facilitate the ECOWAS Free Trade

$$+X_{11,12} + X_{9,12} - X_{12,13} = 0 \text{ flow constraint for node 12}$$

$$X_{12,13} = 1 \text{ flow constraint for node 13}$$

From Aflao to Paga Border exit point.

Objectivity function from Aflao to Paga boarder

$$\begin{aligned} \text{MIN: } & 156.6X_{12} + 28.0X_{23} + 76.9X_{36} + 150.7X_{34} + 563.7X_{69} + 162.4X_{9,11} + 303.1X_{9,12} \\ & + 264.8X_{12,11} + 352.4X_{10,12} + 317.9X_{9,10} + 124.9X_{8,10} + 191.1X_{68} + 216.3X_{84} + \\ & 80.8X_{54} + 230.3X_{57} + 62.5X_{87} + 41.3 X_{11,13} \end{aligned}$$

Decision Variables

X_{12} = the distance travelled from node 1(Aflao) to node 2 (Tema)

X_{23} = the distance travelled from node 2 (Tema) to node 3 (Accra)

X_{34} = the distance travelled from node 3 (Accra) to node 4 (Capecoast)

X_{36} = the distance travelled from node 3 (Accra) to node 6 (Kofiridua)

X_{54} = the distance travelled from node 5 (Takoradi) to node 4 (Capecoast)

X_{57} = the distance travelled from node 5 (Takoradi) to node 7 (Obuasi)

X_{68} = the distance travelled from node 6 (Kofiridua) to node 8 (Kumasi)

X_{69} = the distance travelled from node 6 (Kofiridua) to node 9 (Tamale)

X_{84} = the distance travelled from node 8 (Kumasi) to node 4 (Capecoast)

X_{87} = the distance travelled from node 8 (Kumasi) to node 7 (Obuasi)

$X_{8,10}$ = the distance travelled from node 8 (Kumasi) to node 10 (Sunyani)

$X_{9,10}$ = the distance travelled from node 9 (Tamale) to node 10 (Sunyani)

$X_{9,12}$ = the distance travelled from node 9 (Tamale) to node 12 (Wa)

$X_{9,11}$ = the distance travelled from node 9 (Tamale) to node 11 (Bolgatanga)

$X_{10,12}$ = the distance travelled from node 10 (Sunyani) to node 12 (Wa)

$X_{12,11}$ = the distance travelled from node 12 (Wa) to node 11 (Bolgatanga)

$X_{11,13}$ = the distance travelled from node 11 (Bolgatanga) to node 13 (Paga)

Subject to:

$$0 - X_{12} = -1 \text{ flow constraint for node 1}$$

$$+X_{12} - X_{23} = 0 \text{ flow constraint for node 2}$$

$$+X_{23} - X_{36} - X_{34} = 0 \text{ flow constraint for node 3}$$

$$+X_{34} - X_{45} - X_{48} = 0 \text{ flow constraint for node 4}$$

$$+X_{57} - X_{45} = 0 \text{ flow constraint for node 5}$$

$$+X_{36} - X_{69} - X_{68} = 0 \text{ flow constraint for node 6}$$

$$+X_{57} - X_{87} = 0 \text{ flow constraint for node 7}$$

$$+X_{6,8} + X_{84} + X_{78} - X_{8,10} = 0 \text{ flow constraint for node 8}$$

Road Transportation Model to Facilitate the ECOWAS Free Trade

$$+X_{69} - X_{9,11} - X_{9,12} - X_{9,10} = 0 \text{ flow constraint for node 9}$$

$$+X_{9,11} + X_{11,12} - X_{11,13} = 0 \text{ flow constraint for node 11}$$

$$+X_{8,10} + X_{9,10} - X_{10,12} = 0 \text{ flow constraint for node 10}$$

$$+ X_{9,12} - X_{11,13} = 0 \text{ flow constraint for node 12}$$

$$X_{11,13} = 1 \text{ flow constraint for node 13}$$

Objective Functions for Cote D'Ivoire routes

From Elubo to Kaouara Border exit point.

Objective function from Elubo to Kaouara

$$\begin{aligned} \text{MIN: } & 176.5X_{12} + 176.8X_{13} + 13.6X_{23} + 185.0X_{24} + 194.0X_{45} + 85.2X_{46} + 139.1X_{56} + \\ & 230.5X_{67} + 266.6X_{78} + 137.4X_{58} + 106.0X_{89} + 106.1X_{5,11} + 85.3X_{9,10} + 516.6X_{10,12} \\ & + 228.4X_{11,12} + 109.8X_{12,13} \end{aligned}$$

Decision Variables

X_{12} = the distance travelled from node 1(Elubo) to node 2 (Abidjan)

X_{13} = the distance travelled from node 1(Elubo) to node 3 (Abobo)

X_{23} = the distance travelled from node 2 (Abidjan) to node 3 (Abobo)

X_{24} = the distance travelled from node 2 (Abidjan) to node 4 (Divo)

X_{45} = the distance travelled from node 4 (Divo) to node 5 (Yamoussoukro)

X_{46} = the distance travelled from node 4 (Divo) to node 6 (Gagnoa)

X_{56} = the distance travelled from node 5 (Yamoussoukro) to node 6 (Gagnoa)

X_{58} = the distance travelled from node 5 (Yamoussoukro) to node 8 (Daloa)

$X_{5,11}$ = the distance travelled from node 5 (Yamoussoukro) to node 11 (Bouake)

X_{67} = the distance travelled from node 6 (Gagnoa) to node 7 (San-Pedro)

X_{78} = the distance travelled from node 7 (San-Pedro) to node 8 (Daloa)

X_{89} = the distance travelled from node 8 (Daloa) to node 9 (Duekoue)

$X_{9,10}$ = the distance travelled from node 9 (Duekoue) to node 10 (Man)

$X_{10,12}$ = the distance travelled from node 10 (Man) to node 12 (Korhogo)

$X_{11,12}$ = the distance travelled from node 11 (Bouake) to node 12 (Korhogo)

$X_{12,13}$ = the distance travelled from node 12 (Korhogo) to node 13 (Kaouara)

Subject to:

$$0 - X_{12} - X_{13} = -1 \text{ flow constraint for node 1}$$

$$+X_{12} + X_{23} - X_{24} = 0 \text{ flow constraint for node 2}$$

$$+X_{13} - X_{23} = 0 \text{ flow constraint for node 3}$$

$$+X_{24} - X_{45} - X_{46} = 0 \text{ flow constraint for node 4}$$

$$+X_{45} - X_{56} - X_{58} - X_{5,11} = 0 \text{ flow constraint for node 5}$$

Road Transportation Model to Facilitate the ECOWAS Free Trade

$$+X_{46} + X_{56} - X_{67} = 0 \text{ flow constraint for node 6}$$

$$+X_{67} - X_{78} = 0 \text{ flow constraint for node 7}$$

$$+X_{78} + X_{58} - X_{89} = 0 \text{ flow constraint for node 8}$$

$$+X_{89} - X_{9,10} = 0 \text{ flow constraint for node 9}$$

$$+X_{9,10} - X_{10,12} = 0 \text{ flow constraint for node 10}$$

$$+X_{5,11} - X_{11,12} = 0 \text{ flow constraint for node 11}$$

$$+X_{10,12} + X_{11,12} - X_{12,13} = 0 \text{ flow constraint for node 12}$$

$$+X_{12,13} = 1 \text{ flow constraint for node 13}$$

From Elubo to Pogo Border exit point.

Objective function from Elubo to Pogo

$$\begin{aligned} \text{MIN: } & 176.5X_{12} + 176.8X_{13} + 13.6X_{23} + 185.0X_{24} + 194.0X_{45} + 85.2X_{46} + 139.1X_{56} + \\ & 230.5X_{67} + 266.6X_{78} + 137.4X_{58} + 106.0X_{89} + 106.1X_{5,11} + 85.3X_{9,10} + 516.6X_{10,12} \\ & + 228.4X_{11,12} + 131.1X_{12,13} \end{aligned}$$

Decision Variables

X_{12} = the distance travelled from node 1(Elubo) to node 2 (Abidjan)

X_{13} = the distance travelled from node 1(Elubo) to node 3 (Abobo)

X_{23} = the distance travelled from node 2 (Abidjan) to node 3 (Abobo)

X_{24} = the distance travelled from node 2 (Abidjan) to node 4 (Divo)

X_{45} = the distance travelled from node 4 (Divo) to node 5 (Yamoussoukro)

X_{46} = the distance travelled from node 4 (Divo) to node 6 (Gagnoa)

X_{56} = the distance travelled from node 5 (Yamoussoukro) to node 6 (Gagnoa)

X_{58} = the distance travelled from node 5 (Yamoussoukro) to node 8 (Daloa)

$X_{5,11}$ = the distance travelled from node 5 (Yamoussoukro) to node 11 (Bouake)

X_{67} = the distance travelled from node 6 (Gagnoa) to node 7 (San-Pedro)

X_{78} = the distance travelled from node 7 (San-Pedro) to node 8 (Daloa)

X_{89} = the distance travelled from node 8 (Daloa) to node 9 (Duekoue)

$X_{9,10}$ = the distance travelled from node 9 (Duekoue) to node 10 (Man)

$X_{10,12}$ = the distance travelled from node 10 (Man) to node 12 (Korhogo)

$X_{11,12}$ = the distance travelled from node 11 (Bouake) to node 12 (Korhogo)

$X_{12,13}$ = the distance travelled from node 12 (Korhogo) to node 13 (Pogo)

Subject to:

$$0 - X_{12} - X_{13} = -1 \text{ flow constraint for node 1}$$

$$+X_{12} + X_{23} - X_{24} = 0 \text{ flow constraint for node 2}$$

$$+X_{13} - X_{23} = 0 \text{ flow constraint for node 3}$$

$$+X_{24} - X_{45} - X_{46} = 0 \text{ flow constraint for node 4}$$

Road Transportation Model to Facilitate the ECOWAS Free Trade

$$+X_{45} - X_{56} - X_{58} - X_{5,11} = 0 \text{ flow constraint for node 5}$$

$$+X_{46} + X_{56} - X_{67} = 0 \text{ flow constraint for node 6}$$

$$+X_{67} - X_{78} = 0 \text{ flow constraint for node 7}$$

$$+X_{78} + X_{58} - X_{89} = 0 \text{ flow constraint for node 8}$$

$$+X_{89} - X_{9,10} = 0 \text{ flow constraint for node 9}$$

$$+X_{9,10} - X_{10,12} = 0 \text{ flow constraint for node 10}$$

$$+X_{5,11} - X_{11,12} = 0 \text{ flow constraint for node 11}$$

$$+X_{10,12} + X_{11,12} - X_{12,13} = 0 \text{ flow constraint for node 12}$$

$$+X_{12,13} = 1 \text{ flow constraint for node 13}$$

From Dormaa to Kaouara Border exit point.

Objective function from Dorma / Gonnokron to Kaouara

$$\begin{aligned} \text{MIN: } & 281.5X_{12} + 13.6X_{23} + 185.0X_{34} + 384.7X_{14} + 335.4X_{15} + 194.0X_{45} + 85.2X_{46} + \\ & 139.1X_{56} + 230.5X_{67} + 266.6X_{78} + 137.4X_{58} + 106.0X_{89} + 106.1X_{5,11} + 85.3X_{9,10} \\ & + 516.6X_{10,12} + 228.4X_{11,12} + 109.8X_{12,13} \end{aligned}$$

Decision Variables

X_{12} = the distance travelled from node 1(Dorma) to node 3 (Abobo)

X_{23} = the distance travelled from node 2 (Abobo) to node 3 (Abidjan)

X_{24} = the distance travelled from node 3 (Abidjan) to node 4 (Divo)

X_{45} = the distance travelled from node 4 (Divo) to node 5 (Yamoussoukro)

X_{46} = the distance travelled from node 4 (Divo) to node 6 (Gagnoa)

X_{56} = the distance travelled from node 5 (Yamoussoukro) to node 6 (Gagnoa)

X_{58} = the distance travelled from node 5 (Yamoussoukro) to node 8 (Daloa)

$X_{5,11}$ = the distance travelled from node 5 (Yamoussoukro) to node 11 (Bouake)

X_{67} = the distance travelled from node 6 (Gagnoa) to node 7 (San-Pedro)

X_{78} = the distance travelled from node 7 (San-Pedro) to node 8 (Daloa)

X_{89} = the distance travelled from node 8 (Daloa) to node 9 (Duekoue)

$X_{9,10}$ = the distance travelled from node 9 (Duekoue) to node 10 (Man)

$X_{10,12}$ = the distance travelled from node 10 (Man) to node 12 (Korhogo)

$X_{11,12}$ = the distance travelled from node 11 (Bouake) to node 12 (Korhogo)

$X_{12,13}$ = the distance travelled from node 12 (Korhogo) to node 13 (Kaouara)

Subject to:

$$0 - X_{12} - X_{14} - X_{15} = -1 \text{ flow constraint for node 1}$$

$$+X_{12} - X_{23} = 0 \text{ flow constraint for node 2}$$

$$+X_{13} - X_{24} = 0 \text{ flow constraint for node 3}$$

Road Transportation Model to Facilitate the ECOWAS Free Trade

$$+X_{14} + X_{34} - X_{45} - X_{46} = 0 \text{ flow constraint for node 4}$$

$$+X_{15} + X_{45} - X_{56} - X_{58} - X_{5,11} = 0 \text{ flow constraint for node 5}$$

$$+X_{46} + X_{56} - X_{67} = 0 \text{ flow constraint for node 6}$$

$$+X_{67} - X_{78} = 0 \text{ flow constraint for node 7}$$

$$+X_{78} + X_{58} - X_{89} = 0 \text{ flow constraint for node 8}$$

$$+X_{89} - X_{9,10} = 0 \text{ flow constraint for node 9}$$

$$+X_{9,10} - X_{10,12} = 0 \text{ flow constraint for node 10}$$

$$+X_{5,11} - X_{11,12} = 0 \text{ flow constraint for node 11}$$

$$+X_{10,12} + X_{11,12} - X_{12,13} = 0 \text{ flow constraint for node 12}$$

$$+X_{12,13} = 1 \text{ flow constraint for node 13}$$

From Dormaa to Pogo Border exit point.

Objective function from Dorma / Gonnokron to Pogo

$$\begin{aligned} \text{MIN: } & 281.5X_{12} + 13.6X_{23} + 185.0X_{34} + 384.7X_{14} + 335.4X_{15} + 194.0X_{45} + 85.2X_{46} + \\ & 139.1X_{56} + 230.5X_{67} + 266.6X_{78} + 137.4X_{58} + 106.0X_{89} + 106.1X_{5,11} + 85.3X_{9,10} \\ & + 516.6X_{10,12} + 228.4X_{11,12} + 131.1X_{12,13} \end{aligned}$$

Decision Variables

X_{12} = the distance travelled from node 1(Dorma) to node 3 (Abobo)

X_{23} = the distance travelled from node 2 (Abobo) to node 3 (Abidjan)

X_{24} = the distance travelled from node 3 (Abidjan) to node 4 (Divo)

X_{45} = the distance travelled from node 4 (Divo) to node 5 (Yamoussoukro)

X_{46} = the distance travelled from node 4 (Divo) to node 6 (Gagnoa)

X_{56} = the distance travelled from node 5 (Yamoussoukro) to node 6 (Gagnoa)

X_{58} = the distance travelled from node 5 (Yamoussoukro) to node 8 (Daloa)

$X_{5,11}$ = the distance travelled from node 5 (Yamoussoukro) to node 11 (Bouake)

X_{67} = the distance travelled from node 6 (Gagnoa) to node 7 (San-Pedro)

X_{78} = the distance travelled from node 7 (San-Pedro) to node 8 (Daloa)

X_{89} = the distance travelled from node 8 (Daloa) to node 9 (Duekoue)

$X_{9,10}$ = the distance travelled from node 9 (Duekoue) to node 10 (Man)

$X_{10,12}$ = the distance travelled from node 10 (Man) to node 12 (Korhogo)

$X_{11,12}$ = the distance travelled from node 11 (Bouake) to node 12 (Korhogo)

$X_{12,13}$ = the distance travelled from node 12 (Korhogo) to node 13 (Pogo)

Subject to:

$$0 - X_{12} - X_{14} - X_{15} = -1 \text{ flow constraint for node 1}$$

$$+X_{12} - X_{23} = 0 \text{ flow constraint for node 2}$$

Road Transportation Model to Facilitate the ECOWAS Free Trade

- + $X_{13} - X_{24} = 0$ flow constraint for node 3
- + $X_{14} + X_{34} - X_{45} - X_{46} = 0$ flow constraint for node 4
- + $X_{15} + X_{45} - X_{56} - X_{58} - X_{5,11} = 0$ flow constraint for node 5
- + $X_{46} + X_{56} - X_{67} = 0$ flow constraint for node 6
- + $X_{67} - X_{78} = 0$ flow constraint for node 7
- + $X_{78} + X_{58} - X_{89} = 0$ flow constraint for node 8
- + $X_{89} - X_{9,10} = 0$ flow constraint for node 9
- + $X_{9,10} - X_{10,12} = 0$ flow constraint for node 10
- + $X_{5,11} - X_{11,12} = 0$ flow constraint for node 11
- + $X_{10,12} + X_{11,12} - X_{12,13} = 0$ flow constraint for node 12
- + $X_{12,13} = 1$ flow constraint for node 13

List of Figures

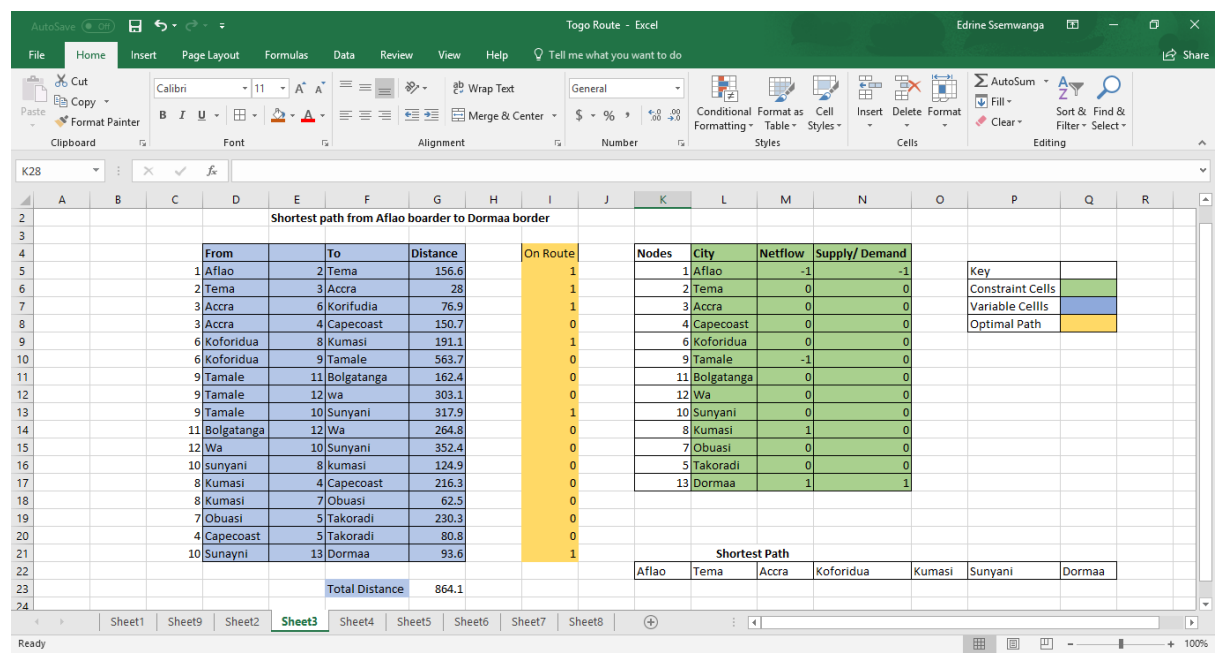


Figure 1.0. A screenshot of a Spreadsheet model for the shortest Path from Aflao border to Dormaa border

Road Transportation Model to Facilitate the ECOWAS Free Trade

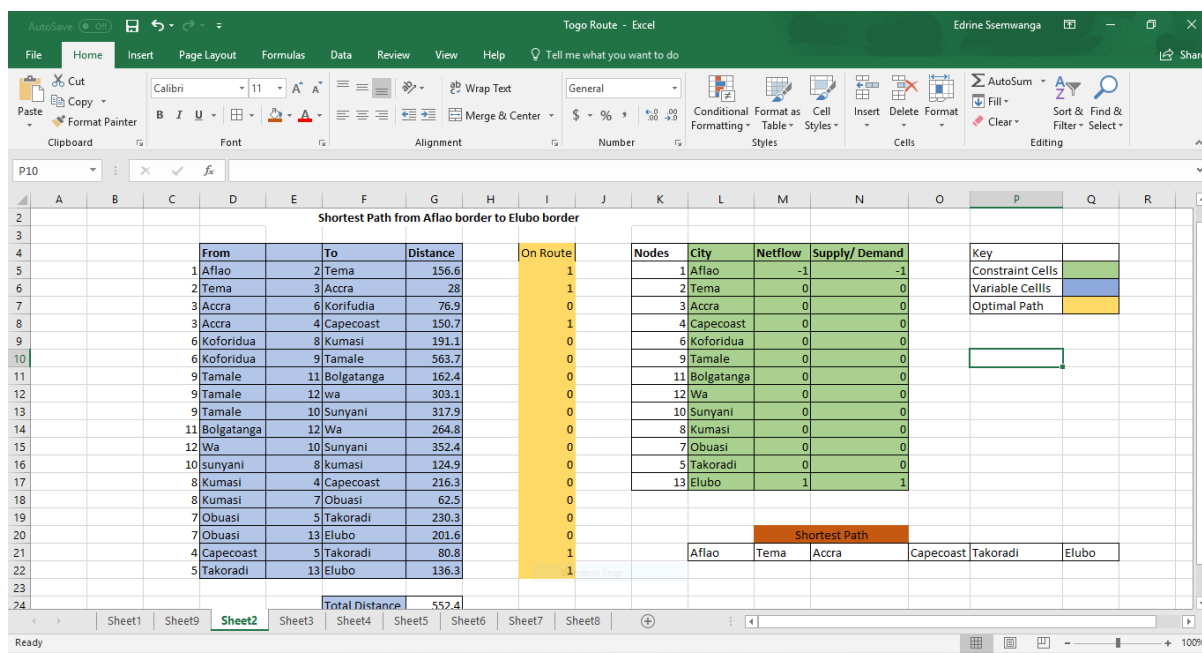


Figure 1.1. A screenshot of a Spreadsheet model for the shortest Path from Aflao border to Elubo border

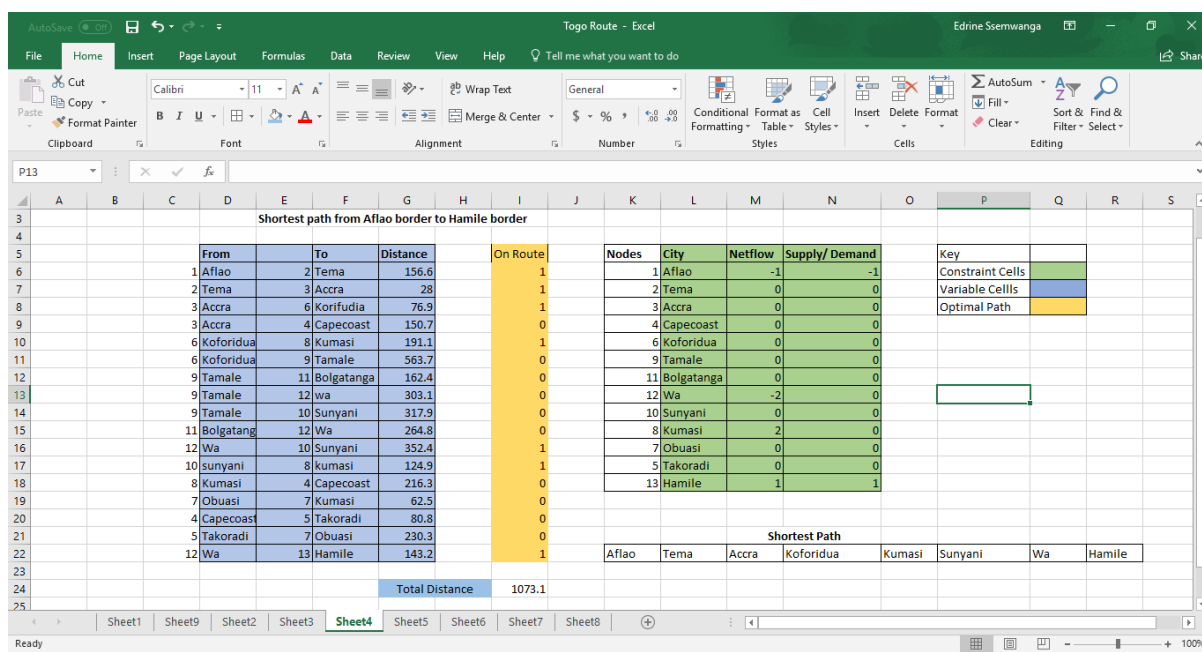


Figure 1.2. A screenshot of a Spreadsheet model for the shortest Path from Aflao border to Hamile border

Road Transportation Model to Facilitate the ECOWAS Free Trade

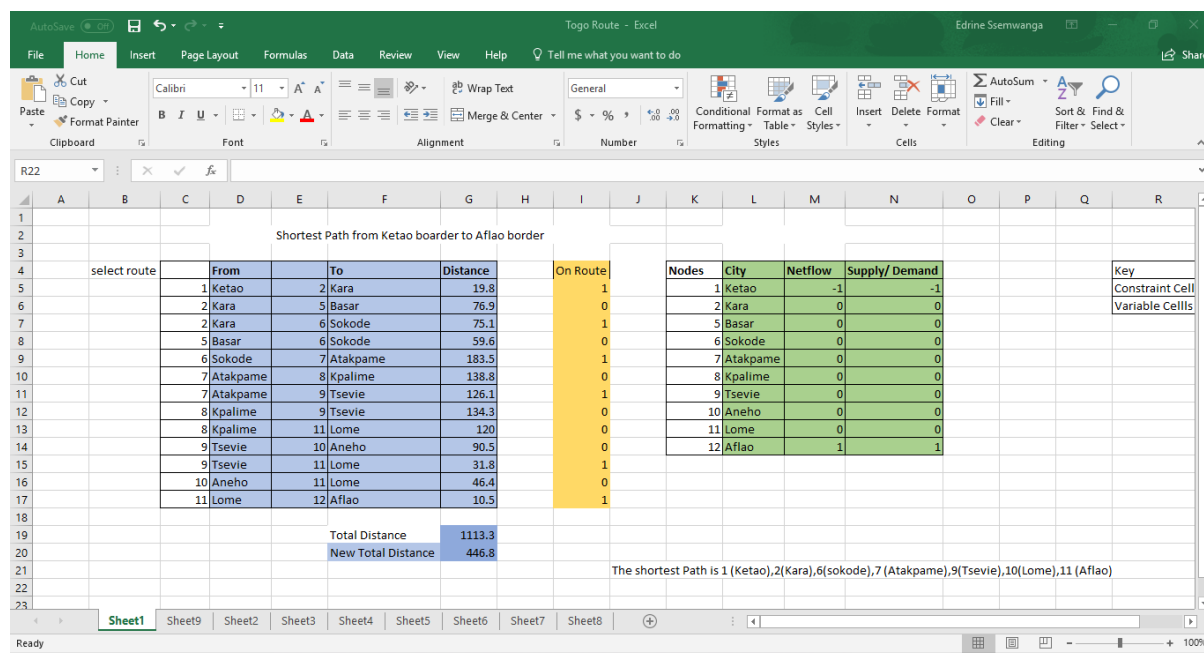


Figure 1.3: A screenshot of a Spreadsheet model for the shortest Path from Ketao border to Aflao border

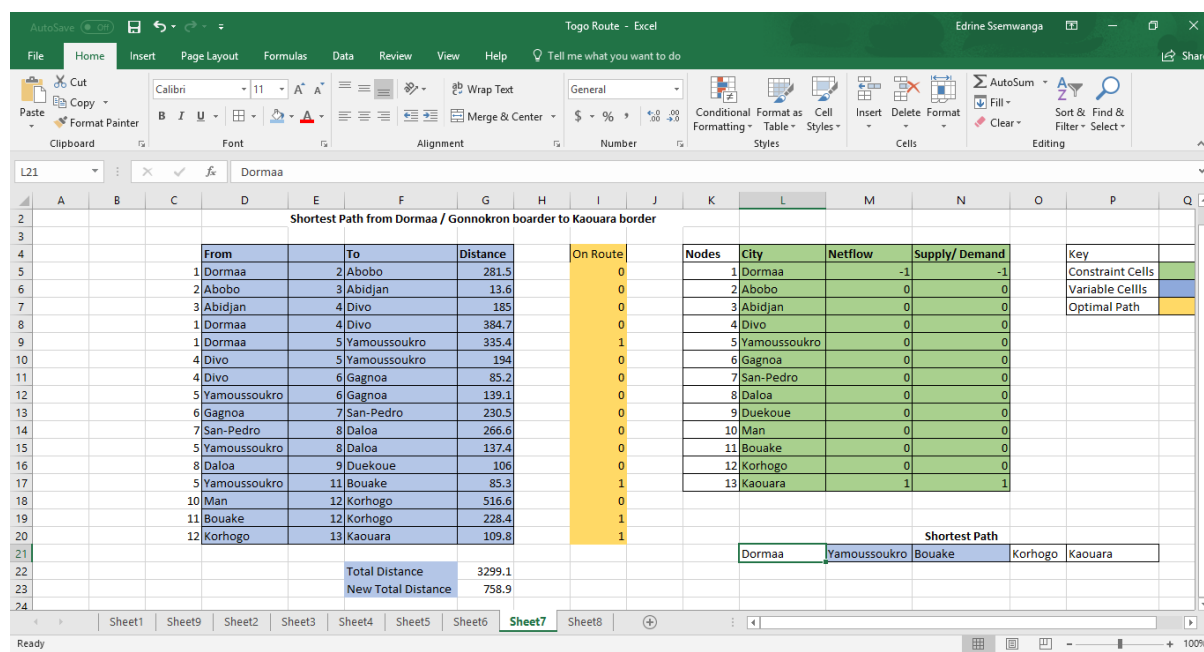


Figure 1.4: A screenshot of a Spreadsheet model for the shortest Path from Dormaa / Gonnokron border to Kaouara border

Road Transportation Model to Facilitate the ECOWAS Free Trade

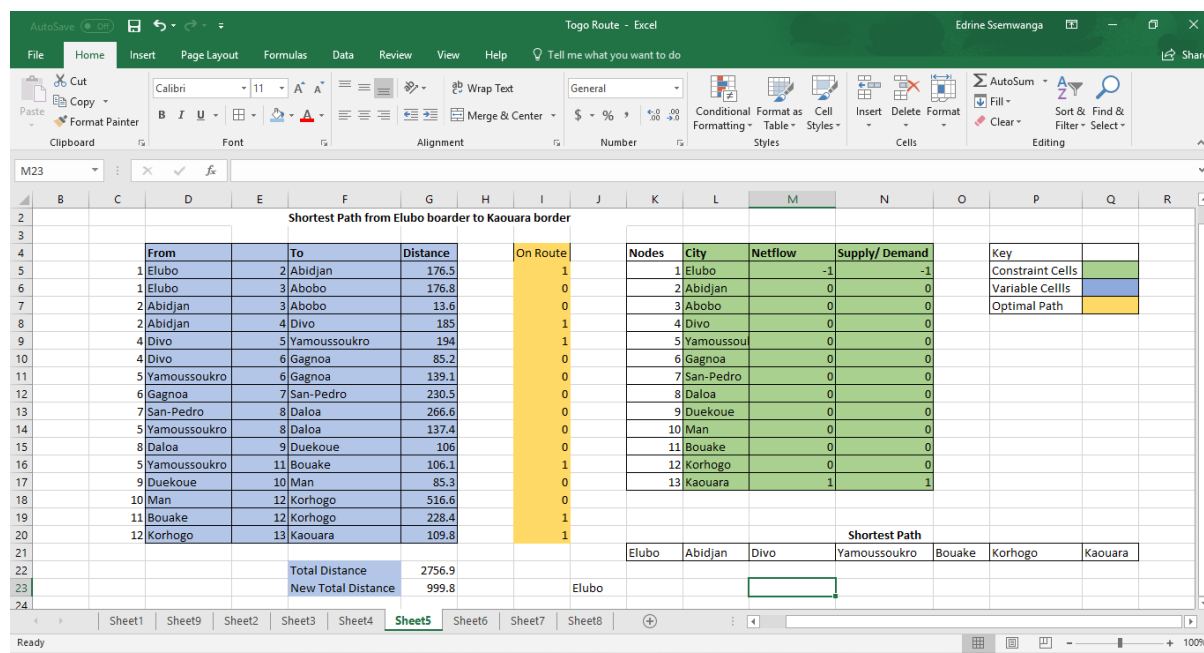


Figure 1.5: A screenshot of a Spreadsheet model for the shortest Path from Elubo border to Kaouara border

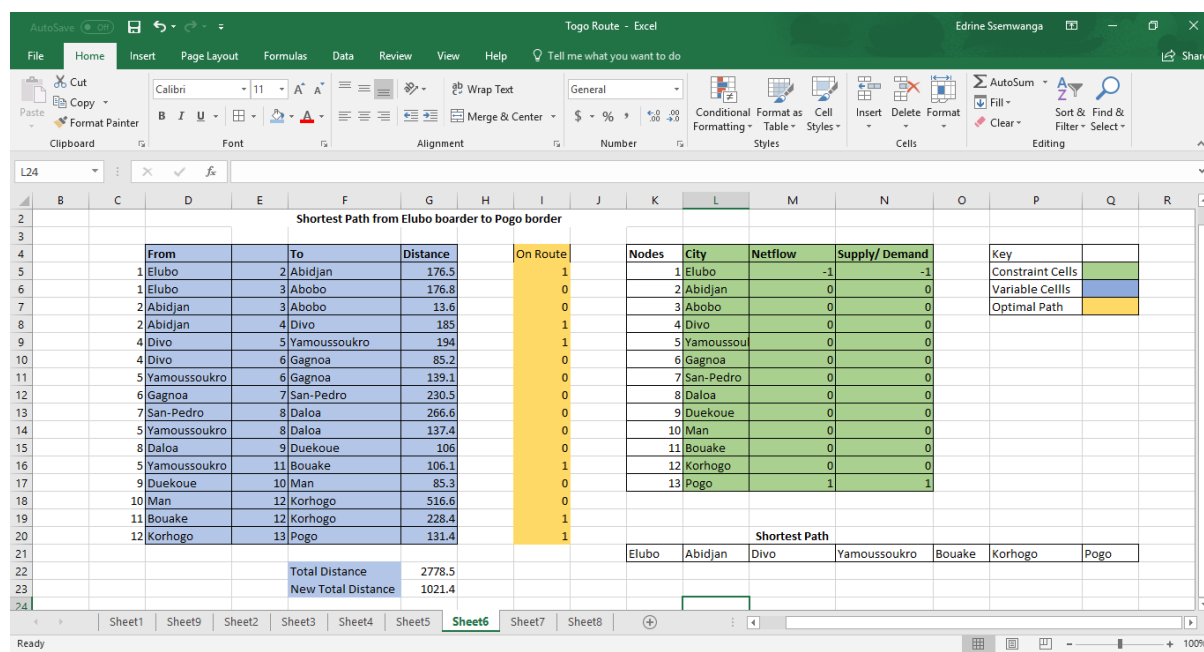


Figure 1.6: A screenshot of a Spreadsheet model for the shortest Path from Elubo border to pogo border

Road Transportation Model to Facilitate the ECOWAS Free Trade

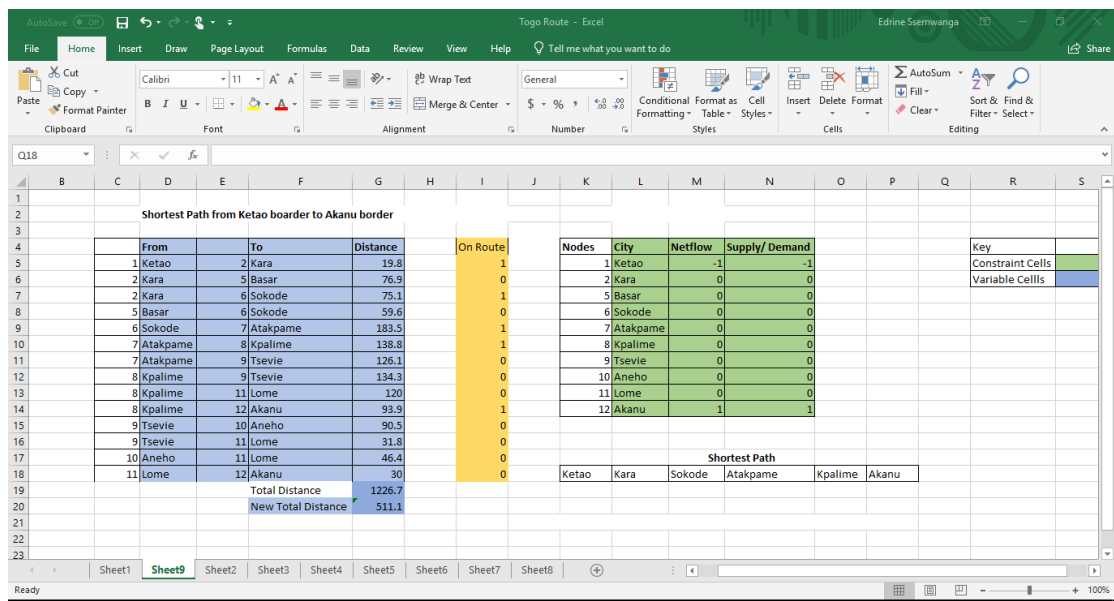


Figure 1.7: A screenshot of a Spreadsheet model for the shortest Path from Ketao border to Akanu border

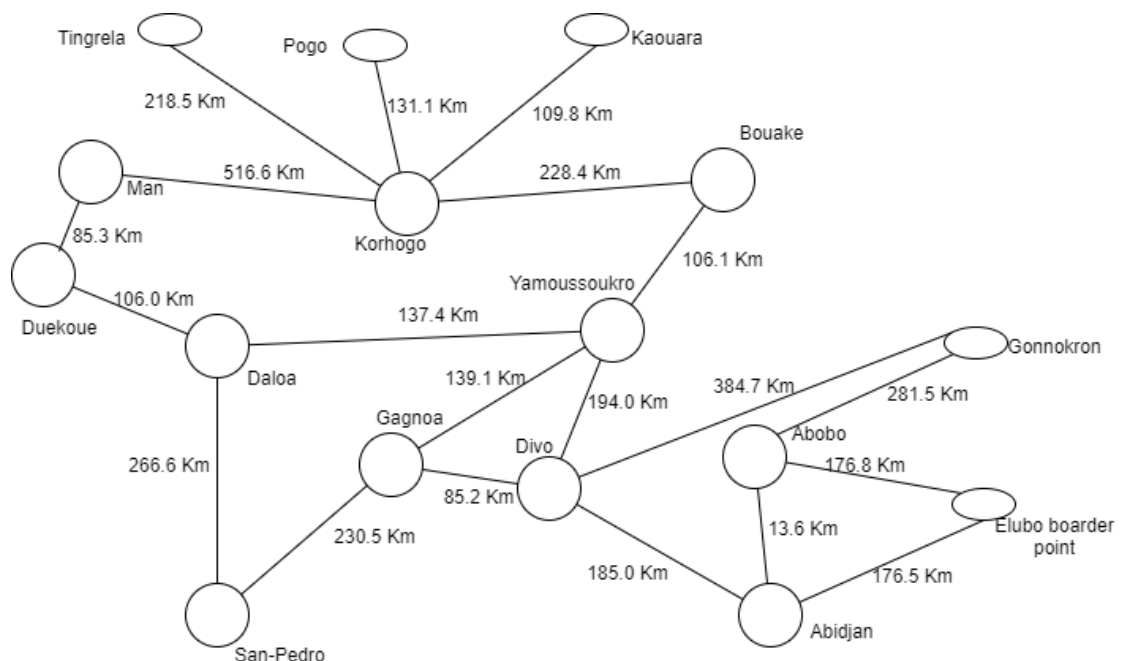


Figure 1.8: A network model of the road transportation network in Cote D'Ivoire showing the various cities and distances connecting them in kilometers.

Road Transportation Model to Facilitate the ECOWAS Free Trade

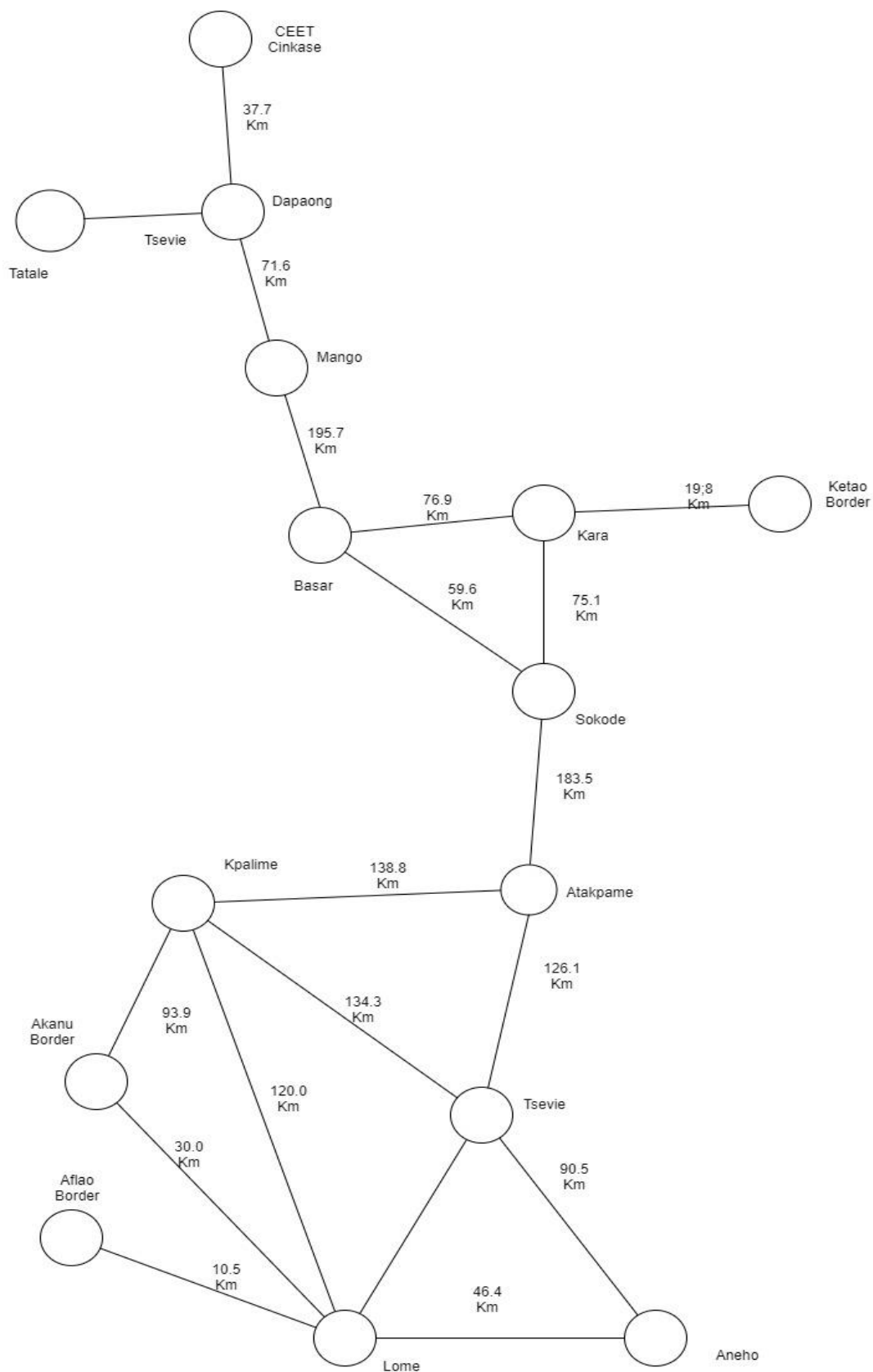


Figure 1.9: A network model of the road transportation network in Togo showing the various cities and distances connecting them in kilometers.



Figure 1.10: An ECOWAS Map showing the ECOWAS countries

Source: www.virutalkollage.com

Road Transportation Model to Facilitate the ECOWAS Free Trade

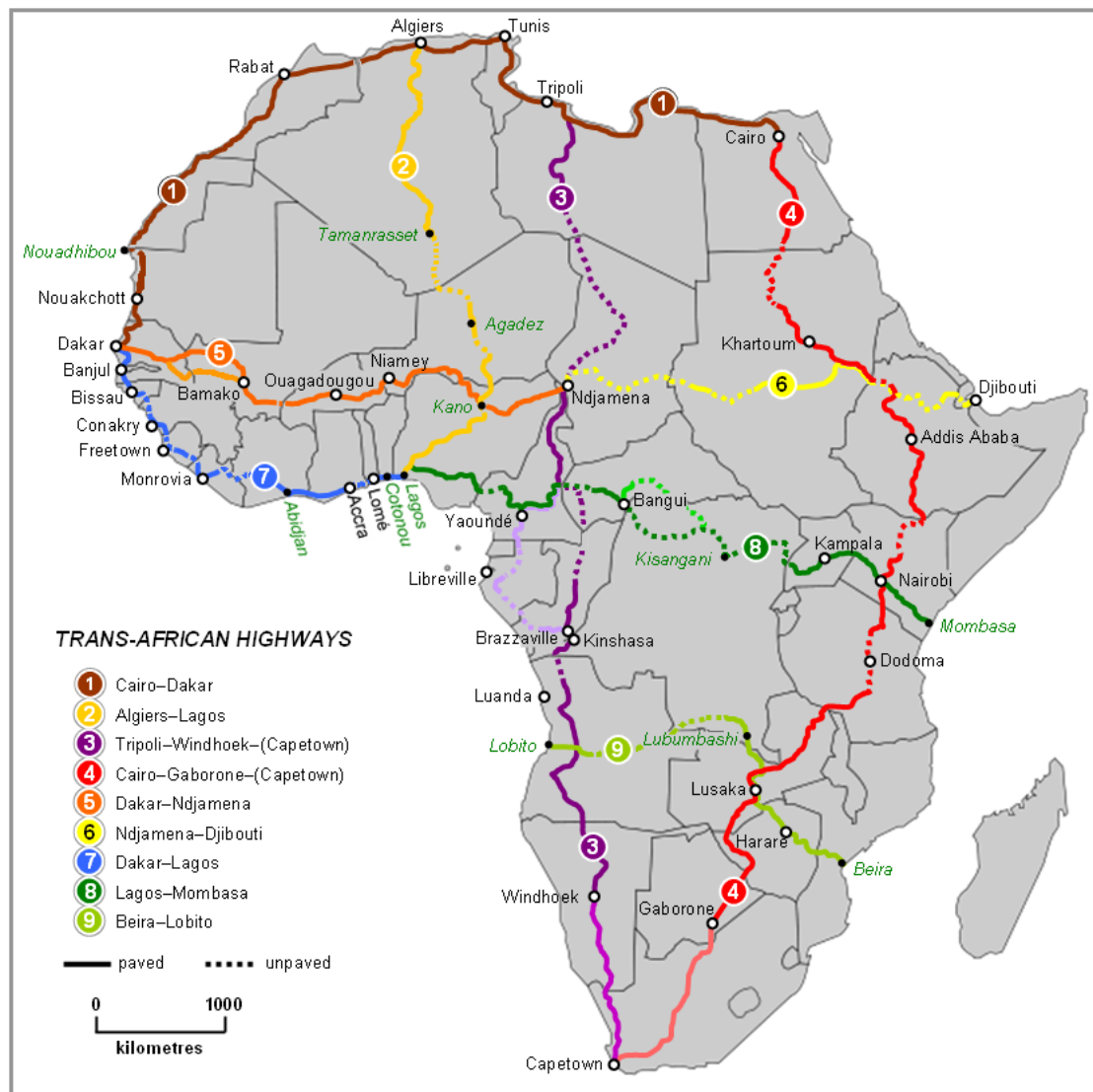


Figure 1.11: A map of Africa showing the Trans-African Highways

Source: en.wikipedia.org

Road Transportation Model to Facilitate the ECOWAS Free Trade

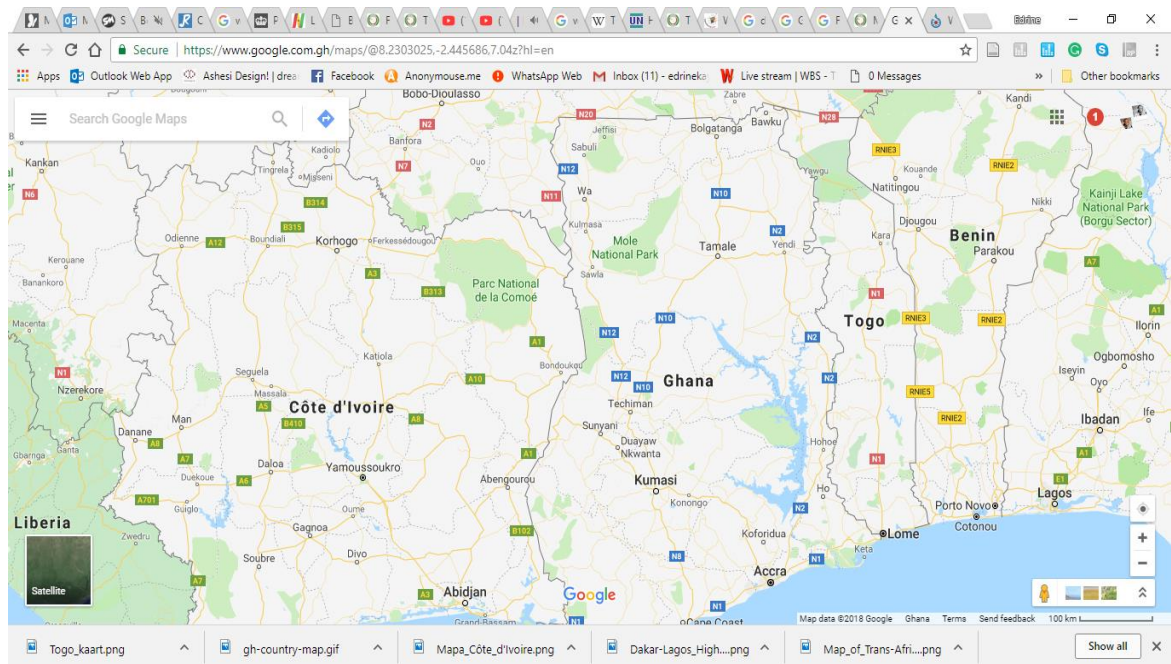


Figure 1.12: A screen shot of the countries under study on Google Maps
Source: googlemaps.com



Figure 1.13: A map of Togo showing some of its major cities

Road Transportation Model to Facilitate the ECOWAS Free Trade

Source: en.wikipedia.com



Figure 1.14: A map of Ghana showing some of its major cities

Source: en.wikipedia.com

Road Transportation Model to Facilitate the ECOWAS Free Trade



Figure 1.15: A map of Cote D'Ivoire showing some of its major cities
Source: en.wikipedia.com



Figure 1.16: A screenshot of a road from Accra to Aflao on Google Maps
Source: Googlemaps.com