OPTIMIZING TRANSPORTATION INFRASTRUCTURE AND GLOBAL-SUPPLY-CHAIN INTEGRATION FOR NICARAGUA'S AUTONOMOUS CARIBBEAN REGIONS THROUGH NETWORK MODERNIZATION

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Optimizing Transportation Infrastructure and Global-Supply-Chain Integration for Nicaragua's Autonomous Caribbean Regions Through Network Modernization

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ABSTRACT

The autonomous regions of the Nicaraguan Caribbean Coast are resource rich, yet they are among the poorest regions of Latin America. To realize economic growth and potential, this research examined Nicaragua's primary-sector economic activities and developed a transportation network that would enable the creation of a functional logistics network, therefore enabling integration into the global supply chain for timber, beef, seafood, and light manufactured goods.

The main goal of this research is to determine the minimum cost of developing a multimodal transportation network in the region by using roads, rail, intracoastal waterways, and Caribbean Sea transport. In addition to the initial construction costs, a 50-year horizon was evaluated, including operation and maintenance expenses for all possible modes as well as the cost to move all goods from point to point within the network using various options per Ton-kilometer. Several sensitivities were also run using Excel Solver in order to determine what triggers would alter the network's construction and operation plan for each transportation arc.

In the aggregate, the least-expensive option, to include deployment of rail, road, and intracoastal waterway use, costs $861,419,624.87 over a 50-year period. This cost captured the initial construction expenses, operation and maintenance estimates, and the rate to move goods across the network; the best-case scenario enabled construction over a 5-year period. More expensive options for the network's construction and operation/movement of goods are more likely given the region's inefficiencies. This research will be given to the Nicaraguan Department of Transportation with the hope that the findings may be used to orchestrate economic and community development in the region.

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DEDICATION

I would like to dedicate this dissertation to the most important people in my life! Thank you, Mom (Dona Betts), for always pushing me to do better and to achieve the very best! To my wife, Alison; son, Miles; and daughter, Siena, thank you for being patient with me and supporting me through this research. Without these four-amazing people, I would never have been able to get here. I am truly grateful to have a wonderful and enduring family!

TABLE OF CONTENTS

ABSTRACT iii

ACKNOWLEDGMENTS iv

DEDICATION v

LIST OF TABLES x

LIST OF FIGURES xi

LIST OF EQUATIONS xiii

LIST OF PARAMETERS xiv

CHAPTER 1. INTRODUCTION 1

1.1. The Importance of Transportation for Economic Development 1

1.2. Background of the Problem 6

1.3. Statement of the Problem 10

1.4. Purpose of the Study 11

1.5. Research Objectives 12

1.6. Significance of the Study 13

1.7. Assumptions, Limitations, and Delimitations 14

CHAPTER 2. LITERATURE REVIEW 16

2.1. Introduction 16

2.2. Overview 16

2.3. Previous Research 17

2.3.1. Transportation-Network Inequality and an Impoverished East 17

2.3.2. With Logistics Capability, what Type of Economic Activity is Possible? 21

2.3.3. Latin American Transportation Investment Effect on Land Use 25

2.3.4. Transportation Network Design 29

2.3.5. Nicaragua Canal and the Associated Infrastructure 33

2.3.6. Supply Chain Improvements 38

CHAPTER 3. METHODOLOGY 45

3.1. Introduction 45

3.2. Research Questions 46

3.3. Study Area 49

3.3.1. Land-Use Change 49

3.3.2. Economic Activity 51

3.3.3. Unintended Consequences 56

3.4. Model 66

3.5. Overall Costs May Not Be Captured in the Model 126

3.5.1. Economic Benefits and Costs to RAAN and RAAS Regions with Transportation Infrastructure 126

3.5.2. Societal Costs as a Result of Land Use Adjustments 126

3.5.3. Energy 131

CHAPTER 4. FINDINGS AND DISCUSSION 132

4.1. Data Analysis 132

4.1.1. La Cruz De Rio Grande to Kukrahill Via Pearl Lagoon 137

4.1.2. El Torugero to Kukrahill Via Camp II Road 138

4.1.3. Pearl Lagoon to the Nicaraguan Road System 138

4.1.4. Bluefields to Punta Aguila 139

4.1.5. Prinzapolka to Puerto Cabeza 140

4.2. Sensitivity Analysis 141

4.2.1. Given the Trucking Rate of $0.17, a Sensitivity Analysis was Conducted via the Model and Yielded the Following Results. 141

4.2.2. Given the Railway Rate of $0.0462, a Sensitivity Analysis was Conducted via the Model and Yielded the Following Results. 143

4.2.3. With a Trucking Rate of $0.17 and the Train Rate of $0.0462, a Sensitivity Analysis was Conducted via the Model and Yielded the Following Results. 144

4.3. Additional Sensitivity Analysis 144

4.3.1. Road-Construction Limits Per Year 145

4.3.2. Adjusting the Discount Rate 148

4.3.3. Bluefields to Punta Aguila Rail-to-Road Transition with a Road-Construction Limit of 63 KM Per Year 150

4.3.4. Inland Waterway Use to Road Transition with a Road-Construction Limit of 100 KM Per Year 153

4.3.5. Road Construction to Fishing Boat or Inland Waterway with a Road-Construction Limit of 100 KM Per Year 156

4.3.6 Relaxing the 5-Year Construction Requirement to 10 Years 159

4.4. Discussion 159

4.4.1. Minimum Cost to Develop a Multimodal Transportation Network in the RAAS and RAAN Provinces 160

4.5. Long-Term Economic Empowerment 164

4.6. Global-Market and Supply Chain Integration 165

4.6.1. Beef 165

4.6.2. Seafood 166

4.6.3. Timber 166

4.6.4. Textiles 168

4.6.5. Cocoa 168

4.7. Other Major Factors to Consider 169

4.7.1. Changes in Commodity Prices Could Affect the Network 169

4.7.2. Environmental and Social Costs 169

CHAPTER 5. CONCLUSIONS AND OBSERVATIONS 171

5.1. Study Results 172

5.2. Quality and Robust Results 173
5.3. Status of the Nicaragua Canal 174
5.4. Exogenous Factors Could Influence Whether the Network is Constructed 174
5.5. Reducing the Logistics “Tax” Placed on Small Transport Companies 176
5.6. Contribution to Literature 177
5.7. Further Research 177
REFERENCES 180

LIST OF TABLES

Table Page

1. Notations used in the study 68

2. Infrastructure costs 87

3. Anticipated expenses for the initial transportation infrastructure 102

4. Hypothetical construction schedule prior to running solver 103

5. Assumed deforestation by municipio 114

6. Length of each transportation arc 123

7. Projected cost to move goods, by arc, over 50 years 125

8. Number of kilometers of road constructed and cabildo connection using all modes 133

9. Type and weight of shipments by origination point annual data 134

10. Construction years and length including each mode 135

11. Weights and year as well as the mode indicating where goods move 136

12. Network costs using multiple configurations based on the regional data 141

13. Minimum kilometers of road construction to meet the five-year requirement 146

14. New suggested infrastructure-construction schedule based on the 63-kilometer constraint 147

15. New suggested infrastructure-construction plan based on the 15% discount rate 149

16. Construction distribution if a road were constructed from Bluefields to Punta Aguila, as opposed to rail, using the 63-kilometer per year road-construction constraint 152

17. Distribution of construction of arcs using road versus waterway arcs 155

18. Distribution of transportation-mode construction with an inland waterway from Pearl Lagoon to Bluefields 158

LIST OF FIGURES

Figure Page

1. Road map of Nicaragua (Perry-Castenada Map Collection, 1997). 8

2. Railway and proposed railway infrastructure in Nicaragua (Long, 1925).......................... 9

3. Waterways in Nicaragua (Styles, 2017)... 10

4. Land-use map of Nicaragua (Perry-Castenada Map Collection,1997). 51

5. Proposed route that connects Tortuguero to a road that will be established (in red) from Camp II to Kukrahill. 75

6. Proposed expansion of the Rio Kukarawala River to the Rio Kurinwas River, enabling cargo traffic to travel to Laguna de Perlas and, subsequently, the port at the southern end. Waterway expansion is highlighted in red. 76

7. Closer view of the proposed river expansion of the Rio Kukarawala to the Rio Kurinwas River for additional river-transport capacity. 76

8. Proposed route that connects Cruz de Rio Grande to Kukrahill via Camp II. 79

9. Map demonstrating the proposed route from Bluefields to Nueva Guinea (light green) and the existing inadequate route from Bluefields to El Rama (IDB, 2014)......... 81

10. Road from Pearl Lagoon connecting to the Nicaraguan interstate system north of Kukrahill. 82

11. Road that will be constructed from Bluefields to Punta Aguila; it will be constructed west and then southeast to avoid as much environmental degradation and swamp land as possible. Should the canal not come to fruition, the deep-water port location may change be based on the assumption that the canal will necessitate a large, deep-water port. 84

12. Road that will be constructed from Prinzapolka to Puerto Cabeza, connecting many communities which are dependent on coastal economic activities; it will be constructed west and then southeast to avoid as much environmental degradation as possible along with the bodies of water where construction is impractical. 86

13. Logistics expenses from farm fate to slaughterhouse (World Bank, 2012a). 95

14. Inefficiencies associated with Central American logistics networks (World Bank, 2012a). 95

15. Average cost in 2013 per rail Ton-km (Organisation for Economic Co-Operation and Development [OECD], 2014). 98

16. Proposed Inter-American Development Bank (2014) road route to connect Bluefields to the Nicaraguan interior. 101

17. Maximum weights per vehicle type in Central America (IDB, 2014). 142

LIST OF EQUATIONS

Equation Page

1. Mathematical formulation for the transportation-network model 67

LIST OF PARAMETERS

Parameter Page

1.1. Road systems as well as potential infrastructure modes that will be built over five years; transportation requirements to meet the long-term demand and regional-modernization needs to enhance the livestock, crop, forestry, and manufacturing sectors 71

1.1.1. Bocana de Paiwas 72

1.1.2. Corn Islands 73

1.1.3. Desembocadura de la Cruz de Rio Grande 73

1.1.4. El Ayote 73

1.1.5. El Rama 73

1.1.6. El Toruguero 74

1.1.7. Kukra Hill 78

1.1.8. La Cruz de Rio Grande 78

1.1.9. Muelle de los Bueye 80

1.1.10. Nueva Guinea 80

1.1.11. Pearl Lagoon 82

1.1.12. Bluefields to Punta Aguila 83

1.1.13. Bonanza 85

1.1.14. Mulukuku 85

1.1.15. Prinzapolka 85

1.1.16. Puerto Cabezas 86

1.1.17. Rosita 86

1.1.18. Siuna 86

1.1.19. Waslala 87

1.1.20. Waspam 87

1.2. Infrastructure costs ... 87

1.2.1. Caribbean Sea transport ... 89

1.2.2. Road-construction cost ... 89

1.2.3. Inland-waterway cost ... 90

1.2.4. Rail cost ... 91

1.2.5. Alternative scenarios: transportation expenses using different configurations and estimates ... 92

1.2.5.1. Trucks ... 92

1.2.5.1.1. High fuel prices ... 93

1.2.5.1.2. Security costs ... 94

1.2.5.1.3. Transferring empty containers ... 94

1.2.5.1.4. Excessive travel times ... 94

1.2.5.1.5. Scarce investment ... 94

1.2.5.2. Trains ... 96

1.2.6. Economic benefit to society ... 98

1.2.7. Factors selected to influence the model ... 99

1.2.8. Short-term transportation requirements to meet canal-construction needs ... 100

1.3. Kilometers of each transportation infrastructure mode by year ... 102

1.4. Discount rate ... 105

1.5. Time ... 106

1.6. Regional economic activities that will contribute to freight type and estimated weights ... 107

1.6.1. Manufacturing ... 107

1.6.2. Forestry ... 113

1.6.3. Cash Crops ... 115

1.6.4. Beef ... 116

1.6.5. Seafood 121

1.6.6. Amount supplied and its contribution to freight scenarios 121

1.7. Transportation mode types.. 122

1.8. Length of each infrastructure mode constructed to meet the requirement to transport supplies from each origin to Bluefields 122

1.9. Cost of moving products from points of origin using different infrastructure types 123

CHAPTER 1. INTRODUCTION

1.1. The Importance of Transportation for Economic Development

Global transportation networks and supply chains are continuously evolving. For over 5,000 years, maritime transportation has ranked among the dominant modes for trade. Recent advances in maritime transportation have revolutionized the methods with which goods are shipped throughout the world. Over the last several decades, global supply chains have evolved as a result of expanded international trade and enhanced transportation networks. Regions of the world which were once outside traditional trade routes are rapidly developing because of new commercial opportunities. As such, almost every country has access to a global economy that is rapidly integrating. In the United States, one can easily cook a meal with produce from multiple nations in the Americas, seafood from Asia, grains from Europe, and dessert/coffee using commodities from west Africa; this meal may be served on dishes from Portugal, using utensils from India and cloth napkins from Bolivia, while sitting at a table which was made at a manufacturing facility in China and on chairs from Indonesia.

The autonomous regions of eastern Nicaragua are well positioned to contribute to global markets given their vast quantity and quality of resources; however, the provinces lack the requisite transportation infrastructure to move goods that are harvested and/or processed in the region. In 2015 when this research was initiated, the Chinese and Venezuelan governments were beyond the initial planning and design stages for a major canal project. The Nicaraguan Canal project was chosen (a) to accommodate supertankers which are too large for the Panama Canal and (b) to reduce American geopolitical hegemony in the Western Hemisphere. Without the Nicaraguan Canal, the easternmost provinces of Nicaragua would still dramatically benefit from economic and social growth due to transportation investments. This dissertation assumes that the canal will be constructed. The lessons are still applicable without the canal given the need to integrate this relatively poor region into global supply chains. Nicaragua has abundant assets that would propel its population from poverty if they were developed effectively using modern transportation modes.

Given the trade trends to accommodate an integrated world economy, there is a fundamental need for increased maritime transportation infrastructure to support approximately $18 trillion in annual global trade. The Panama Canal Authority, with infrastructure which is over 100 years old, invested in a major expansion that began in 2006. The projected global maritime-infrastructure requirements may support the creation of another interoceanic canal. Rodrigue, Notteboom, and Slack (2017) estimated that 90% of all global trade occurs in the maritime space. The transformation in trade is largely due to technical improvements, comparative and absolute advantages, and economies of scale. Future trade requirements may lead to the construction of larger cargo vessels. The new Nicaraguan Canal was planned to accommodate these larger ships because the expanded Panama Canal might not have the capacity to support the new, upsized container ships. The current proposal for a Nicaraguan canal may fit the new global-trade requirement and may provide a viable trade alternative for the Panama Canal.

New infrastructure investments in eastern Nicaragua would not only advance global trade opportunities, but also enable one of Latin America’s most impoverished nations to reform its transportation infrastructure. New export opportunities have enabled underdeveloped regions in the world’s poorest countries to modernize. Although nations and private industry primarily focus on elements associated with enabling commerce, such as expanding port capacity, warehousing, airports, and the railroads and roads connecting manufacturing activity to facilities used in the supply chain, the people of these countries have realized economic and infrastructure benefits, e.g., paved roads and increased incomes. Growth has been especially true for nations such as Egypt, Haiti, and Panama given their involvement with maritime trade space (Embassy of Egypt, 2016). Nicaragua is positioned to benefit from similar transportation modernization patterns, thereby enhancing the domestic logistics' capacity and international supply chain integration.

In addition, developing nations have realized non-monetary benefits from global trade. Investments in transportation infrastructure have served as an enabler for an improved quality of life. International trade reduces consumer prices and can lead to improvements in the quality of goods sold. Many countries which have modernized as a result of transportation investments have also expanded primary and secondary education opportunities for their populations; constructed new medical facilities, thereby expanding healthcare; and, in some cases, reduced economic inequalities (Oquist, 2016).

This dissertation will focus on transportation-infrastructure investments as well as growth-and-development opportunities in the eastern, autonomous regions of Nicaragua. Eastern Nicaragua is among the poorest and least-developed regions of Latin America. Throughout its history, the region has been neglected due to its ethnic makeup and geographic isolation. The autonomous regions of the Miskito Coast have very little access to markets in either Nicaragua or Central America; as a result, the area is severely underdeveloped in terms of economic activity and infrastructure development. There are no roads that connect the southern region to Managua or other commercial centers in the region, and the port infrastructure cannot accommodate deep-water requirements. In addition, transportation costs are very high due to the lack of infrastructure, older equipment, and inefficiencies. Without intensive investment from the central government in Managua or an economic catalyst, the autonomous regions will likely continue to be mired in poverty. The proposed Nicaraguan canal could be the catalyst which is necessary to modernize the region with investments for transportation modalities and the associated infrastructure as well as the immigration of a new skilled workforce. This new transportation capacity would improve the logistical capacity for moving livestock, crops, and other time-sensitive products while enabling the potential to integrate Nicaraguan products which originate from these regions into global supply chains and networks. Although the canal is not required for this network to come to fruition, it is important to briefly understand the proposed canal's benefits.

There are several historic examples of nations that developed as a result of constructing interoceanic canal systems. Since 1956, Egypt has benefited economically from the Suez Canal. Some estimates indicate that up to 10% of Egypt's gross domestic product (GDP derive from canal revenues (Embassy of Egypt, 2016). Supporting transportation infrastructure, such as tunnels connecting the Sinai Peninsula to the Egyptian mainland, contributes to the nation's economic development. In Panama, the canal has enabled the creation of special economic zones and incorporation into various global supply chains; Panamanians manufacture goods for transnational corporations and ship throughout the world via the canal. In addition, some revenue from the canal is earmarked for social development, such as increased education funding and improving national healthcare facilities (Autoridad del Canal del Panama, 2016); a majority of the development projects occurred post U.S. occupation because domestic investment has been a priority for the new canal zone vice the old order managed in the United States.

Like Panama and Egypt, Nicaragua can unlock its economic development potential with this megaproject. With a project of this scope and size, Nicaragua can invest in significant port, highway, and rail infrastructure and can develop economic sectors that will utilize this infrastructure and the resulting increased access to global markets. Much of this development will assist the previously isolated areas of eastern Nicaragua. As in Panama and Egypt, an outside superpower, China in this instance, is proposing the project and is willing to finance a significant portion of the construction as well as the initial operation and maintenance expenses. Successful project implementation will create tens of thousands short-term jobs and, hopefully, modernize the Nicaraguan economy, thus enabling the creation of permanent employment.

It is important to highlight that the proposed Nicaragua canal project is getting off to a rough start. The global economic downturn, coupled with acute losses in the Chinese stock market, have prevented Chinese investors from beginning the project. Constantini (2016) believes that the Panama Canal's recent expansion, coupled with a highly speculative return on investment (ROI), may account for the project's demise. International concerns regarding project financing, a lack of feasibility and vulnerability assessments, low construction estimates, and other hurdles also contribute to the planners' challenges. There are domestic concerns in Nicaragua that create obstacles for constructing the canal. Accusations about communication shortcomings between the residents of the autonomous regions and the central government in Managua have led to distrust between planners and citizens; land-use and environmental effects throughout the nation, labor availability, energy access, and material shortfalls continue to dominate political discourse, thereby making the project less likely. If the money were available for this project, many domestic, political disagreements must be worked out prior to construction. Estimates for canal construction range from $50 billion to $100 billion (HKND Group, 2014. This price does not include the unintended costs associated with the environmental effects and relocating tens of thousands of people.

Whether the project comes to fruition, researching and analyzing the potential for multimodal transportation improvements in the nation's eastern half will be highly beneficial for economic developers and non-governmental organizations (NGO) that operate in the region. This study will contribute to supply chain development for various economic sectors in the region and will provide a blueprint for the least-expensive and most-efficient approach for developing transportation modalities and capacity. The natural resources and their proximity to global markets are in place. With adequate transportation infrastructure, Nicaragua's least-developed and most-isolated regions could realize similar benefits as the ones observed in Panama and Egypt.

1.2. Background of the Problem

At the time of this writing, there is very little paved-road infrastructure in eastern Nicaragua. There are a couple highways that lead to the capital from the northern Caribbean coast; however, a majority of the region's inhabitants do not have access to paved roads. This situation creates major difficulties for regional growth and development. It is important to note that the lack of infrastructure creates a tax for small companies which currently export beef, timber, or crops due to transportation costs which are over twice as high as what larger firms enjoy (World Bank, 2012).

Historically, eastern Nicaragua has been left behind by people who have governed the nation. For the most part, this disparity is due to ethnic tensions between the Afro-Caribbean east and the Mestizo west (L. Sanchez, 2007). Separatist movements, geographic isolation, linguistic differences, and the coast's low population density have further aggravated the relationship with legislators in Managua. As such, remoteness from Nicaragua's population centers, coupled with a desire to remain autonomous, has led to a lack of infrastructure investments in the eastern areas. There is very little transportation infrastructure in eastern Nicaragua, especially on the Miskito Coast. Paved roads can also be used to modernize the region by creating opportunities for global supply chain integration in sectors such as ranching, crop production, and mining. These same roads could be used to support the Nicaragua canal's development because large trucks and equipment would use the network.

Figure 1 illustrates the Nicaraguan highway network. The two roads that enable shipments from the eastern half of the nation to the Caribbean Sea, Nicaraguan Highways 7 and 21B, are unable to accommodate the requirements for moving heavy machinery, e.g., a 10-ton road (Perry Castenada Map Collection, 1997). Although someone driving a car could access Managua and the remaining large cities in Nicaragua, the same does not apply to large construction operations. The challenge becomes even more acute when one examines the port infrastructure at Punta Aguila; energy, vehicles, and other project-related materials require a deep-water port. In addition, there is no fuel-refining capacity in eastern Nicaragua, adding to the logistical complexities for any economic activity in the region.

Figure 1. Road map of Nicaragua (Perry-Castenada Map Collection, 1997).

Railway transport in Nicaragua was suspended in 2001. Since the 1972 earthquake in Managua, the government has struggled to maintain the rail line. Like the road system, the railway primarily serviced Managua and points west; historically, Pacific Coast ports benefited given their capacity to move goods to the country's major population centers. In the east, there was a private line leading to Puerto Cabezas; however, this line did not connect to major commercial centers in the west. There was a proposed rail from Lake Nicaragua to the Caribbean Coast which closely followed the canal route, but construction never came to fruition. In Figure 2, this proposal is highlighted in the southeast corner of the map. In addition, it is important to emphasize that no major changes occurred since the map was developed in 1925, indicating the railway's low priority for the government's transportation planners.

Figure 2. Railway and proposed railway infrastructure in Nicaragua (Long, 1925).

Although there are significant obstacles with respect to roadways and railways, navigable waterways present a significant advantage for the project. Infrastructure would require investment, however, because fluvial navigation is underdeveloped. Styles (2017) writes that large vessels can navigate through most of the nation’s waterways from May through October;

November through April is the dry season and inhibits full transport. In addition, waterways in the Caribbean basin tend to be larger and longer. Opportunities for navigable-waterway investment to assist with the large transportation needs for this project are observed in Figure 3.

Figure 3. Waterways in Nicaragua (Styles, 2017).

1.3. Statement of the Problem

Eastern Nicaragua does not have the transportation infrastructure needed to achieve its economic potential. There is an inadequate transportation infrastructure in eastern Nicaragua to facilitate basic commerce outside of Bluefields; Puerto Cabeza fairs slightly better because there is a route of various secondary roads that eventually lead to the nation’s population centers in the west. Constructing the Nicaragua canal cannot occur without significant transportation-infrastructure investments in the nation’s eastern, mostly southeastern, quadrant. Long-term logistic development and supply chain integration with global markets will depend on a combination of transportation modes in the region.

1.4. Purpose of the Study

The study’s purpose is to determine the most cost-effective and feasible transportation-investment options to meet the long-term transportation demand for a modernized eastern Nicaragua, with or without the Nicaragua canal project. In the short term, the canal megaproject may import a number of construction inputs, such as refined and unrefined fuels; massive amounts of earthworks; and construction materials, e.g. concrete. The country will have to feed, shelter, and serve tens of thousands of workers in temporary cities.

In the long term, a modernized region will experience the growth and development of global supply chain contributions for markets involving agriculture, cattle ranching, mining, new industries, and light manufacturing. These industries will require the transportation infrastructure to ship their products to the country’s commercial centers and also export items to other nations. In addition, with lower unemployment rates and a higher standard of living, there will be a demand for modern conveniences that include consistent electricity, new housing developments, and transportation modes that enable a higher quality of life. This study will not only analyze the feasibility associated with the new transportation infrastructure, but will also examine land-use changes and the long-term effects associated with growth and development. Nations that have experienced similar growth and development in recent decades, e.g., Belize and Brazil, will be used as comparative examples.

1.5. Research Objectives

The principal objective of this research is to develop a plan for a minimal cost, multimodal transportation network in the North Caribbean Coast Autonomous Region (RAAN) and the South Caribbean Coast Autonomous Region (RAAS). This network will enable the movement of goods and services while supporting full economic and societal opportunities. The different steps included with this model's development are as follows:

1. Enumerating the long-term transportation requirements necessary to enable communities throughout the RAAN and RAAS to realize their full economic potential. Industries such as tourism, crop and livestock production, seafood harvesting, mining, light manufacturing, and trade will be included with this plan.
2. Detailing the costs associated with constructing alternative transportation modes. Suitable infrastructure investments will be identified, and estimates of their capital and operating costs will be obtained from international literature.
3. Building a minimum-cost optimization model to determine the lowest-cost solution to construct, operate, and travel on a multimodal network over a 50-year period.
4. Assessing the sensitivity of the minimum-cost model to changes in the key parameters, such as differing transportation costs for various construction modes, road-construction length constraints, discount-rate adjustments, and thresholds for the cost to move goods across the network by Ton-km.
5. Stating pertinent conclusions and observations for Nicaraguan transportation planners and economic developers.

1.6. Significance of the Study

This research may have a significant influence on economic-development and transportation planners in Nicaragua. Should actual construction begin on the canal, economic developers, private industry, and transportation planners must be prepared to harness the new waterway's positive economic consequences. This study's largest contribution will be the return on investment associated with transportation-infrastructure options, such as road, rail, and river options, and their respective short- and long-term effect on Nicaraguan land use, export opportunities, economic modernization, agricultural development, and the improved standard of living. By focusing on a number of transportation modes, a viable determination can be made to, first, capture the least-expensive and most-efficient transportation options for near-term requirements and, second, ensure long-term economic success for the region as a result of the new transportation capacity.

Should the canal project not come to fruition, planners will have the optimal transportation network as well as least costly solution for economic and social development. This research is effectively a blueprint that would enable growth using transportation, global supply chain integration, and logistics as the catalysts.

Historically, there has been some research on integrating the autonomous regions with the rest of Nicaragua; however, modernization through transportation investments has not been examined beyond a few white papers and studies which were conducted by the central government and organizations such as the World Bank. The dissertation specifically examines how to logistically support the Nicaragua canal project using road, rail, or river transport; this study includes a recommendation of multimodal use due to the potential long-term effect on land use and the ability for the autonomous regions to realize sustainable economic-development prospects. This research also presents opportunities for local industry, such as manufacturing and agriculture, and its respective contributions to regional and global supply chain networks.

The research and analysis of transportation construction options and their respective short- and long-term economic effects will be shared with the government of Nicaragua and local universities. It is hoped that the research will be used to make the most cost-effective decisions necessary to propel the Atlantic Coast and its residents into the 21st Century. In addition, the analysis of transportation modalities will assist local and central government authorities with their decisions to finance projects; transportation options are quantified, thereby enabling decision makers to determine the best courses of action and returns on investment.

1.7. Assumptions, Limitations, and Delimitations

Given that the canal is conceptual, this study will rely upon current estimates of the infrastructure that the canal's construction project will entail. In addition, each variable used to determine how the transportation project, as well as economic growth, is likely to occur will include assumptions and limitations based on regional and historic trends. Furthermore, due to political instability and difficulties with visiting this region, the research will proceed using publicly available information.

Another limitation is based on an inability to travel to Nicaragua to collect primary data. A request was made so that the researcher could travel to Nicaragua and conduct a few focus groups, examine microeconomic studies with local university staff in Bluefields, and discuss economic-growth opportunities with regional business owners. After seven months of consideration and speaking with four different departments and offices, a senior adviser made the decision to not permit the data collection due to the researcher's past work in Army intelligence.

This dissertation will use qualitative and quantitative data to determine the inputs which are necessary to develop a minimum-cost model for developing and constructing a transportation network that meets regional needs. Before discussing the model, a Literature Review will describe the body of knowledge concerning transportation in the region as well as the area's logistic networks.

CHAPTER 2. LITERATURE REVIEW

2.1. Introduction

This Literature Review serves two academic purposes. First, it aims to identify the current state of science in relation to optimization models for transportation networks. Some of the reviewed studies are from technical sources (grey literature) that will augment academic research in order to ensure that both theory and practical applications are captured. Also, some of the examined literature is published in Spanish and is included in this study.

Second, the review of literature presents previous research about transportation, logistics, and supply chain challenges that have prevented eastern Nicaragua from realizing its full economic potential. The review then transitions into how constructing the Nicaragua canal would affect local supply chains and expand logistic capabilities into the region. In addition to the economic and transportation-network realities of eastern Nicaragua, the field of transportation network design is explored because there are a number of studies which have minimized the cost of developing a network within similarly underdeveloped regions of the world. There are also several studies that have modeled the maximization of profit within transportation networks in developing countries; those projects have a similar potential as the Nicaraguan model.

2.2. Overview

This Literature Review is divided into six sections. The first section focuses on Nicaragua's current transportation network to various modes, such as roads and waterways. Because a majority of the nation's transportation infrastructure is in the western two-thirds of the nation, the east has struggled to develop economically. The next section focuses on what economic and social development is possible if transportation infrastructure was developed as a result of the canal project. This section concentrates on the economic potential, given natural resources and current industry, and the potential effect on land use.

The first three sections of the Literature Review focus on the current situation, what is possible with transportation-infrastructure investment, and what occurred in Latin-American nations with similar economic and climate conditions. The latter three sections focus on the proposed transportation infrastructure as a result of the canal and the global supply chain improvements as a result of Nicaraguan industry coming online. Section four outlines previous transportation studies that focused on network design; including both maximization of profit modeling and minimum-cost models. Several of these studies occurred in developing countries and provide lessons learned for Nicaragua. Section five highlights what is planned to support both the project's short-term construction requirements and long-term viability, e.g., road construction and integration into the Nicaraguan highway system. The last section focuses on what industries may grow and develop because of new infrastructure as well as how products from eastern Nicaragua can influence global supply chains and logistic networks.

2.3. Previous Research

2.3.1. Transportation-Network Inequality and an Impoverished East

Nicaragua is both the largest and least-developed nation in Central America. As a result of limited financial resources and the majority of its population living in the western half of the nation, the country's entire eastern half has been neglected from an infrastructure-development perspective (Perry-Castaneda Map Collection, 1997). As such, no road network exists, cutting off the southern Caribbean coast from the rest of the nation's economic opportunities. It is certainly possible that massive investments from the Nicaragua canal project will not only expand economic and infrastructure-development opportunities, but also open up new supply chains for various industries, including agriculture and manufacturing (Inter-American Development Bank, 2014).

For people in the autonomous regions of Nicaragua, a lack of transportation capacity, e.g., a domestic road network, has led to abject poverty. L. Sanchez (2007) conducted 181 interviews in the two autonomous regions of Nicaragua in 2003 and 2004; he used secondary data and concluded that ethnic tensions between the Afro-Caribbean east and Mestizo west have led to distrust and separatist movements. In addition, the English-speaking east has few linguistic and cultural similarities with the Spanish-speaking west, leading to few federal investments in the region. L. Sanchez writes that over 90% of the population living in the autonomous west is dissatisfied with government services. Having no road network has limited economic growth and development due to supply chain challenges as well as a lack of access to goods and services.

The lack of rural development, mostly caused by transportation and domestic-connectivity shortcomings, has led to staggering economic problems. According to Pitsch and Ritzenhaler (2001), unemployment has been as high as 80% and can easily average well above 50%; the economy is very informal, and like most developing nations, workers seek employment opportunities abroad. With regards to economic activity, there is only the fishing industry and a small degree of tourism. Just inland, there is an abundance of agricultural and mining opportunities, but no road system. In essence, there are two Nicaragua's (Gabriel, 1996) as a result of the economic and transportation/infrastructure disparities.

Currently, there are no paved roads which connect communities along the southern half of the Caribbean coast. Bluefields, the largest city in the region, is only accessible via air or sea. There are navigable waterways that lead to El Rama in the interior, but from there, roads are still inaccessible to the remainder of the nation. There are plans to build a national highway system when resources become available (Republic of Nicaragua, 2005)

To facilitate trade and the movement of goods, alternative overland-transportation concepts have also come to fruition in the country, and there is the potential for expansion to the Caribbean coast. In Muzira and Hernandez de Diaz (2014) “Rethinking Infrastructure Delivery: Case Study of a Green, Inclusive, and Cost-Effective Road Program in Nicaragua,” *adoquines*, or paving stones, have become a viable alternative for expensive road construction. Because resources are scare, using *adoquines* is expected to improve connectivity and access to the country’s Atlantic region. *Andoquines* are a much less-expensive method to build roads given cost-prohibitive bituminous asphalt. According to Muzira and Hernandez de Diaz (2014), alternative road-sector construction has led to economic benefits for agricultural producers and transporters along with other ancillary benefits. The research team worked with the World Bank and dozens of localities in Nicaragua in order to determine the extent of the *adoquine* system along with maintenance plans. In addition, all eight *adoquine* manufacturing firms were consulted as part of this research.

In addition to academic research concerning transportation-infrastructure inequalities, there are several organizations which have studied the region, augmenting journal articles with practical applications for the economic effects. Several international non-government organizations, aid agencies, and multinational development banks continue to study poverty-reduction strategies; implementation of local programs is frequent but has a limited influence on the regional economy. The International Monetary Fund (2010), in close cooperation with the Nicaraguan government, concluded that the emphasis on transportation improvements in Nicaragua focuses exclusively on transportation subsidies for the western part of the nation and improving the existing roads in and around Managua. As such, except for the canal project, there is not much hope for transportation improvements along the Atlantic coast.

The Nicaraguan government, however, has identified the need to assist people living along the Caribbean coast. In its *National Development Plan* (Republic of Nicaragua, 2005), the government highlights the need to not only build roads leading to Bluefields, but also to deploy investments that will assist with moving people and merchandise, thereby creating opportunities for logistical movements throughout the country. As the region develops economically, it will enjoy new export opportunities, including the movement of goods and services to western Nicaragua where a majority of the population resides. An infrastructure investment could create industrial growth in agriculture and mining along with the distribution networks necessary for the successful marketing and sales of regional products. The national plan was substantiated by contributions from several government agencies and legislatively defined goals using data which were collected throughout the nation. In addition, non-governmental groups contributed to this report, adding a third-party perspective. Data were collected using central-government employees, and a majority of the analysis was conducted in the capital's ministry offices.

At present, airports and a small port at Bluefields are what enable economic activity in the region. Without road networks or a functional railway, it is essential that new infrastructure be constructed for the region to realize its full economic potential. According to the Government of Nicaragua (2017), a major financial catalyst or project would provide the resources needed to develop a national infrastructure; although the idea surfaced a few years later, the Nicaragua canal may be the conduit for new transportation development.

2.3.2. With Logistics Capability, what Type of Economic Activity is Possible?

Nicaragua's Atlantic coast has been underdeveloped for centuries. As a result, there are very few domestic and international economic activities that the population can utilize. There are several industries that could experience tremendous growth if transportation and logistics networks were developed (World Bank, 2012b). Supply chains (or inclusion into existing networks) for various industries would then form due to the need for a relatively quick export of either raw material or agricultural commodities in order to meet regional and global demand. Given the current economic model and the propensity for existing industries to expand because of the enhanced logistics capacity and domestic/global supply chain integration, it is more likely than not that industries such as cattle ranching, fishing, and forestry will realize short-term benefits, therefore expanding more quickly than other potential sectors such as manufacturing. This assumption is based on current resources, generations of occupational patterns, and what followed in nations with similar climates and economic conditions.

Finley-Brook (2007) discusses the economic and administrative benefits of a strengthened logging industry and a network of exporters if the appropriate conditions exist. Access to both financial and commodity-trading markets would bring development and stability to the Atlantic coast. According to Finley-Brook, the sector has had a tumultuous history; a lack of political order, brought on mainly by economic disparity, has led to instability. With a road network and exporting capacity, it is highly probable that logging firms would establish a presence and become part of a larger supply chain. According to Finley-Brook's research, there is a wide variety of forest life that could be utilized for responsible harvest and export. Finley-Brook collected most of the study's data using results from a University of Richmond field support team in addition to many anonymous interviews with local residents. Based on research conducted on land use in Belize and Brazil, it is likely that after logging operations, cattle ranching will ensue in most places given the new land-use opportunity.

Van Der Vorst, Da Silva, and Trienekens (2007) focused their research on food supply chain networks and the effect on overall logistics. Overall, baseline systems and procedures would be established, followed by functional integration of materials and physical distribution. Internal integration using a logistics-management model would then occur prior to external integration with suppliers up the chain. In Van Der Vorst et al.'s (2007) research, having the ability to produce and sell locally would drastically reduce the dependence on foreign agriculture to feed developing-nation population centers. Enhanced food supply chain networks would lead to functional planning and process improvements for growers and producers, production planning and scheduling/tracking for food processors, reduced prices for wholesalers due to a consistent supply, and ensured delivery of products to retailers for sale to consumers.

Much of Van Der Vorst et al.'s research focused on a similar supply chain analysis in the developing world. Van Der Vorst et al.'s (2007) case studies focused on supply chains including, but not limited to, pork production and sales in China, fresh produce in Thailand, beans in Central America, and dairy products in Brazil. All of these nations and the supply chain challenges paralleled how baseline systems could be established and deployed in eastern Nicaragua if there were both canal and road development. Fortunately for the region, new agricultural production capacity will be a major boon to the local economic conditions that will foster lower unemployment rates.

In addition to academic research concerning logistic channels and supply chains, there are several organizations which have studied the region. The government also outlines a few exporting opportunities should transportation and infrastructure investments occur in the Atlantic region in its "*Proposal Submitted for the Consideration of the Global Agriculture and Food Security Program*" (Republic of Nicaragua, 2017). This document describes how to incorporate the nation's most impoverished regions into both supply and value chains. The Atlantic coast has tremendous agriculture potential. Incorporating small farmers from the eastern regions could increase both yields and exporting capacity due to access to the tools necessary to enlarge farms. Data for this study came directly from government agencies responsible for the country's poverty reduction and agricultural production. If history in Latin America is any indicator, large commercial operations will develop as well; these companies will then look to transport their product via new road (or rail) networks to ports for immediate export.

The proposal also highlights the foreign direct investment that is possible in the agricultural sector should the necessary logistic networks be developed and implemented (Republic of Nicaragua, 2017). Logistic networks are dependent on the construction of a road network that the government highlights as essential to the region's macroeconomic performance. Movement in the network would come in the form of both agricultural exporting and domestic consumption that are coupled with forestry harvesting. The government also engaged in economic modeling to demonstrate that the region was the nation's most impoverished area. Although extremely poor and underdeveloped, with the requisite investment into transportation networks, the region has the potential to grow efficiently and quickly. Economic development potential is due to the available natural resources that could quickly join the regional marketplace; proceeds from these sales could then cycle back into the coastal economy, especially for smaller operations.

In addition to the Nicaraguan study, the World Bank (2012b) examined the effect of a rural road network in western Nicaragua; the road was maintained exclusively by women and was funded using foreign aid. In this work, women did a better job maintaining the roads than their male counterparts. In a traditionally patriarchal society, gender roles were modernized as income became available. Because these roads were maintained, community economies improved due to the logistical network (World Bank, 2012b). Road construction and maintenance could be applied to the Atlantic region if investments were made. The eastern political departments would realize access to markets and other institutions that have influenced growth and development for the rest of the nation. Additional household income would also improve the local quality of life. The World Bank piloted rural road networks in several countries by using female labor; the results for nations that participated in this project were positive across the board, with an improved local quality of life. As such, the pilots were local; data collection was on site; and the results for these proofs of concept were analyzed for whether road maintenance performed by women exceeded the quality of men’s work.

There are many examples of successfully implementing logistical networks and supply chains as a result of transportation improvements and maintenance. In addition to agriculture, there are several mining, manufacturing, and other activities that could come to fruition with the appropriate infrastructure. As a bonus, if the canal were built, there is the potential for a refinery to be built on the Caribbean coast, leading to opportunities for domestic consumption and regional export. According to the HKND Group (2014), the energy industry is seriously considering the region for a refinery, leading to the potential for a highly diversified economy. These jobs would initially require skilled labor, but as the industry matures, it is possible that many Nicaraguans will study the appropriate vocational programs in order to gain semi-skilled and skilled employment that pays more than agriculture.

2.3.3. Latin American Transportation Investment Effect on Land Use

The autonomous regions of eastern Nicaragua have the potential to not only grow and develop economically, but also to transform the methods with which land is used. If accomplished responsibility and methodically, Nicaragua can enjoy growth while avoiding the mistakes that other nations in the region made. There are several countries in Central and South America that have similar geographic profiles, climates, and existing land uses to which we could compare. Northern Belize is one area that benefited from transportation-infrastructure investments and modernization efforts; in addition, Brazil experienced tens of billions of dollars in infrastructure investments because of *Avanca Brasil*, or Advance Brazil (World Bank, 2012b).

As a result of the new transportation infrastructure, several spillover effects occurred, affecting Brazilian environments. In some areas, deforestation became a major problem given the new access to roads which led to markets. In addition, the areas that were cleared became prime land for cattle ranching. Jusys (2016) argued that, in Brazil's Pará state, cattle ranching was the largest contributor to Amazon deforestation. Using geographically weighted regression modeling from economic distances versus the Euclidean model, Jusys also found a strong correlation between official/unofficial road construction and deforestation in the nation's remote areas. Because Nicaragua's eastern regions share similar geographic and economic characteristics, it would be prudent for land-use planners to prevent a similar fate. Jusys also found a weak correlation between crop cultivation and deforestation.

Mertens, B., Poccard-Chapuis, R., Piketty, M. G., Lacques, A. E., & Venturieri, A. (2002) discovered similar results to Jusys although the primary contributor to deforestation resulted from developing roads, followed by cattle ranching. Using spatial analysis focused on livestock economies, Martens et al. determined that two-thirds of the deforestation occurred within 50 kilometers of the new highways which were built as part of *Avanca Brasil*. Using a logit model and Landsat imagery that spanned from the 1980s into the 1990s, it became evident that soybean production and cattle ranching led to a four-decade period of rapid deforestation. Laurance, W. F., Cochrane, M. A., Bergen, S., Fearnside, P. M., Delamônica, P., Barber, C., ... & Fernandes, T. (2001) went a step further and determined that road networks have enabled ranchers, colonists, and industrial logging firms to expand into Brazil's interior. Over the last several decades, the non-indigenous population in the interior grew tenfold from 2 million to 20 million. With almost $40 billion of road, highway, and hydroelectric investments, *Avanca Brasil* may have contributed to economic modernization, but it also contributed to Laurence et al.'s estimate of losing 28-42% of Brazil's pre-Colombian forest by 2020!

In addition to spatial modeling and analysis, econometric research has also proven Amazonian deforestation. Pfaff (1999) developed an econometric model that focused on rates of Brazilian deforestation in the 1970s and 1980s, and he determined that the greater the road density, the greater the loss of forests. This research examined other nations in the Amazonian region and found similar patterns that resulted from infrastructure construction and development.

Land-use changes resulting in environmental degradation and a loss of forest are not isolated to the Amazon. In Belize, a nation with a very similar climate and Central American, rural economic model, similar patterns were evident. In their spatial-modeling research of northern Belize, Wyman and Stein (2010) found that cattle was the lead driver for deforestation. Like Brazil, similar patterns emerged with respect to infrastructure development and subsequent land uses. At present, there are large cattle operations in central Nicaragua (the western edge of the Southern Caribbean Autonomous Region) and a similar land profile throughout area. As such, Nicaraguan planners would have to take land-use into account when developing new land-use policies in order to avoid similar environmental destruction. Like Laurance et al. (2001) and their Brazilian focus, Wyman and Stein (2010) found that approximately 30% of the Belizean study region was deforested. Areas that were riparian and ones that had road construction over the last several decades were almost as destroyed as places with significant cattle operations.

Chomitz and Gray (1996) conducted similar research in Belize and found results akin to Wyman and Stein. In their research, Chomitz and Gray determined that market access and distance to roads strongly affect the probability of agricultural use, especially for commercial enterprises. The research also yielded a strong positive correlation between development and land clearing in Belize’s forests. Rural road construction promoted impressive economic development prospects, given new opportunity, but facilitated the region’s deforestation as a spillover effect.

Not all researchers who have studied economic growth in Brazil and other developing nations with similar geographic and infrastructure-development profiles believe that there is a clear connection between development and deforestation. Weinhold, D., & Reis, E. (2008) Reis (2010) agreed that there was a positive correlation with economic development and subsequent destruction of the forest; however, using dynamic modeling as opposed to static models, Reis found that, in areas that were already partially cleared, decreasing transportation costs resulted in lower rates and speeds of deforestation. Weinhold, D., & Reis, E. (2008) and Reis (2010) studied data at the *municipio* (township) level, as opposed to the aggregate level, and discovered that some areas which saw an intensification of cattle ranching also had a decrease in new land clearing. In essence, Reis argued that urbanization in formerly rural areas of the Brazilian Amazon required new skills sets and occupation types, thereby leading to less land clearing.

In prior research using similar dynamic-modeling techniques, Andersen, L. E., Granger, C.W., Reis, E.J., Weinhold, D., & Wunder, S. (2002) also found that levels of deforestation were dependent on the amount of partial clearing that occurred prior to construction. If there were substantial clearing to enable growth and development of a community, Andersen et al. determined that new roads would reduce the risk of land clearing. Angelsen and Kaimowitz (2009) took these philosophies a step further and stated that a correlation between road construction and deforestation in Brazil was too simple of an explanation. Spatial analysis may have been incorrect in its assumption that road construction led to deforestation. The causality may have been settling in the road as well as development and a subsequent requirement for road construction after the deforestation occurred rather than initial construction. The immediate causes of deforestation may be institutions, infrastructure, and markets; however, the underlying cause is most likely macroeconomic in nature.

Pfaff, A., Robalino, J., Walker, R., Aldrich, S., Caldas, M., Reis, E., ... & Kirby, K. (2007) took a different approach and retested Andersen et al.'s (2002) findings using census-tract-level data. Pfaff et al. used a similar method to test the data, but it was more locally based given that the research was conducted using census tracts versus *municipio*-level data. The re-evaluation found that lower transportation costs via roads increased deforestation by 50-75% in some communities. *Avanca Brasil* added several thousand kilometers of road, but some communities were environmentally devastated by these new roads.

Nicaraguan planners have the ability to leverage significant lessons which were learned from Belize and Brazil. Like the affected regions in these nations, eastern Nicaragua is dependent on small-scale and commercial agriculture. If global-market export opportunities come to fruition with the new infrastructure, land-use planners should utilize historic examples to assist with the efforts to maximize economic benefits while reducing the propensity for environmental destruction. Monitoring the environment is especially critical because it is likely that many municipalities in the autonomous regions will experience deforestation based on the anticipated ranching expansion.

2.3.4. Transportation Network Design

Historically, network design and transportation planning have been critical for successful economic development and growth initiatives throughout the world. Transportation infrastructure could be the catalyst for growth in all industrial sectors and is vital for poverty-reduction initiatives. As eastern Nicaragua designs and deploys a transportation network, regional planners should leverage available research. Fortunately, the latter half of the 20th century had major advances in optimization modeling because computer power increased. As algorithms became more robust in the 1970s and 1980s, transportation planners and academics began to leverage additional computational power in order to solve complex challenges (Xiong and Schneider, 1992).

Magnanti and Wong (1984) reviewed a number of network-design models in order to synthesize the models, to propose a new framework for deriving models, and to summarize computational experiences for designing problems in order to improve transportation planning. Their research used an integer-programming-type model and discovered that the model was highly useful to assist developing countries with planning new transportation infrastructure. The research observed general network-design models using the same basic variables (ingredients), e.g., a set of "N" nodes and "a" arcs. Overall, operational decisions as well as tradeoffs and available resources determined which arcs were selected by the planners, thereby creating the maximum benefit for the least cost in the model. Overall, Magnanti and Wong analyzed a number of existing optimization models, as well as various programming methods which were available to planners, and concluded which approaches were the most effective.

A few years later, Xiong et al. (1992) furthered the research about developing network-design models by identifying how the available algorithms to find optimal solutions were deficient. In their research, Xiong et al. discovered that two main challenges existed for the available algorithms: one, computing-time requirements for discrete transportation-network designs were too large; and two, systems were unable to process multiple criteria simultaneously. To mitigate these challenges' influence, researchers used the neural network to develop a Discrete Transport Network Design Problem (DTNDP). The DTNDP involved selecting new facilities (links within the network) to add to an existing transportation network in order to ensure that, moving forward, capital investments would be optimal. There were several reasons that led to historic challenges within the transport-network design algorithms prior to the 1990s: the size led to inadequate computational power; the branch-and-bound approach was handled more effectively with a smaller network design; heuristic algorithms handled larger networks, but computational requirements were high; and relationships among the performance values associated with the optimal solutions could not be determined. After these challenges were identified, the researchers recommended introducing new constraints, creating a new definition for the DTNDP as well as its relationship to various transportation networks and sizes, and furthering research to test the performance of the cumulative genetic algorithm used in neural networks.

Yang and Bell (1998) significantly added to the body of research through a major review of transportation-network design models. They determined that network design problems (NDP) had been difficult to design until the 1980s and 1990s. Difficulties were due to a number of factors, such as computational power, advances in transportation, and limited algorithm development. Yang and Bell focused their research on making optimal transportation-investment decisions while minimizing overall travel costs. To achieve optimality, a bi-level NDP framework was created. The primary level focused on the level of service using the existing economic activity, transportation capacity, traffic flows, and performance and management. The second level examined capacity, utilizing a management system and level of investment to ensure as much accuracy as possible.

An NDP using the bi-level framework was created to determine optimal network-investment decisions using a cost-minimization approach. The framework also examined maximizing the reserve capacity within the road network. Variables included, but were not limited to, users' transport costs throughout the network, total construction costs, and vehicle miles traveled. After developing the framework, Yang and Bell (1998) explained that previous and future NDP studies should be compared to realistic road networks in order to determine optimality. A need to continue and to further the research on algorithm development was also highlighted.

Expanding on the network design problem, Ukkusuri, Mathew, and Waller (2007) focused on traffic-network design with demand uncertainty. Using a number of origin and destination matrices as random variables, several probability distributions were developed. When robustness accounting was introduced, a formulation of a robust network design problem (RNDP) using a genetic-algorithm (GA) methodology was utilized for the model. Ukkusuri et al. found that their research departed significantly from deterministic network design problems because not accounting for the system's robust nature underestimated the network-wide effects.

To explore the efficacy of this new approach, different budget levels were used to test the algorithm, yielding successful results.

As computer processing improved after the 1990s, many transportation networks were designed and built in developing countries. In total, there was a mixture of profit-maximization models focused on increasing the economic output within networks as well as cost-minimization models in nations with fewer transportation options than developed countries. As such, this Literature Review includes two recent studies which were conducted developing countries with parallels. Bozkaya, B., Yanik, S., & Balcisoy, S. (2010) focused their research on using a Geographic Information Systems (GIS)-optimized framework to solve a multi-facility routing problem. In central Turkey, a major company constructed a massive node that serviced multiple locations. When compared to the Nicaraguan transportation network, the node is Bluefields, and the locations are the municipalities and cities serviced by the central node. Bzkaya et al sought to maximize profit by using a probabilistic-patronization-of-customers model along with the routing costs for the central depot. Considering eastern Nicaragua, economic development and patronization of the road system was estimated because there are no hard numbers suggesting freight amounts or travel use. For the profit-maximization problem, a heuristic-optimization methodology was developed and used to map the best locations within the GIS application.

Pribadi, D. O., Putra, A. S., & Rustiadi, E. (2015) focused on new growth centers which were based on regional economic-development disparities in Indonesia. Interestingly, there were many parallels to eastern Nicaragua because investment into economic and transportation programs focused on the nation’s specific areas. Like Managua and points west, Indonesian centers of growth had economic development and a transportation policy for modernization. Java was the primary beneficiary of transportation investments, whereas the rest of the country seemed to have inadequate transportation-network designs and the subsequent resources required to grow. Pribadi et al. created an inter-regional input-output optimization model to generate maximum economic performance. The objective function was to minimize the deviation of economic growth and to improve household income by using transportation policy and investments.

Constraints for the Indonesian transportation-network development model included, but were not limited to, demand for services, land availability for crops, available labor, export and import capacity, and a variety of value-added opportunities to regions. Supply for this model focused on regional production capacity at various locales in Indonesia. Like this dissertation's Nicaraguan focus, many similar economic-development requirements, focusing on agriculture, labor, and export and import capacity, surfaced. With respect to constraints, each region was served by a center of origin. In the aggregate, Pribadi et al. (2015) determined the optimal value of development targets by province. Optimal input and output flows were also created.

In the case of Nicaragua, there are many parallel economic- and transportation-development requirements. Using a similar approach, a transportation-investment cost-minimization model is developed, reflecting similar characteristics as the Indonesian study.

2.3.5. Nicaragua Canal and the Associated Infrastructure

Public-Private Partnerships (PPP) have a deep history in Latin America, especially as it pertains to road and rail projects. Estache, A., Guasch, J. L., Iimi, A., & Trujillo, L. (2009) highlight that over $180 billion has been invested globally via PPP frameworks since the 1990s; with over $72 billion being invested Latin America. Nearly one half of the PPP investment has been in rail and road projects. To augment the trend, Hartwich, F., González, C., & Vieira, L. F.

(2005) indicate that PPP is rapidly becoming the dominate source of infrastructural investment in Latin America.

Results regarding performance of the PPP model vary by nation. Strong legal frameworks as well as financial institutions, specifically those that have set aside funds for public-private projects, appear to have a much higher success rate than nations who do not have these mechanisms in place. For example, the Inter-American Development Bank (2017) found that of four approved projects in the Dominican Republic, only one was funded and subsequently implemented. The failure was due in large part to inadequate legal protections as well as a government attempt to collect shadow tolls along proposed infrastructure (Inter-American Development Bank, 2017).

Successful models have been deployed. In Colombia, the government strengthened the regulatory framework, created funds specifically for PPP initiated projects and implemented its Fourth Generation Toll Program. Of the 40 project applications, the World Bank (2016) indicated that 19 were funded and began shortly thereafter. Other Latin American nations such as Peru and Argentina have similar success in road, rail, ports and inland waterway infrastructure; primarily due to legal frameworks as well as financial institutions prepared to support PPP projects.

There was over a 100-year gap between the initial research to determine if Nicaragua could host a transoceanic canal and the idea presented by the HKND Group to construct a canal. As such, academic research about the infrastructure that would accompany a project of this magnitude was non-existent. However, there were several technical studies which address the canal and the likely transportation infrastructure that would augment and follow the project. Constructing the Nicaragua canal would have a transformational effect on the national and regional economies in Nicaragua. This new maritime shipping channel would also be the catalyst for land transportation-infrastructure investments, e.g., roads and bridges. Given the plethora of agricultural and manufacturing opportunities available along the Atlantic coast, the canal will potentially create new supply chains to feed both domestic and international consumption requirements for food and natural resources (HKND Group, 2016).

Oquist (2016) believes that Nicaragua will experience major poverty- and inequality-reduction opportunities throughout the nation as a result of canal construction. The canal has the potential to add enough commerce and infrastructure development to generate 8-10% economic growth per year. This number pertains to national-level economic growth; given the underdeveloped east, it is quite feasible that growth could be larger given how far behind the region is when compared to the rest of the nation. As part of the canal, Nicaragua has agreed to expand its free-trade zones to resemble those of Panama (Oquist, 2016). In addition, both coasts would see major investments for ports such as Brito and Aguila. Port development would not only create jobs, but also offer export opportunities for mining, agriculture, and energy, all industries which could benefit the Atlantic region if the appropriate supply chains existed.

According to Oquist (2016), the Nicaraguan Gross Domestic Product could double with the creation of 1.2 million jobs because of this project. This progress could all occur within a decade. The project would also assist with environmental restoration along the Caribbean coast, which could lead to more tourism-industry opportunities. According to the government's estimate, the canal would reduce deforestation trends and help to reclaim land along the coast while producing tens of thousands of construction jobs. Oquist has direct contact with the Ortega government and the HKND Group, the firm building the canal. He is able to source data unlike other researchers due to his portfolio in the national government and his involvement with the project’s leadership team. In addition, it is important to note that the HKND Group and the government of Nicaragua have been relatively opaque with respect to data access.

HKND Group (2016), the company responsible for financing and constructing the project, also anticipates major economic growth and activity as a result of the project. Given the project’s needs, permanent road construction leading to Puerto Aguila would come to fruition. New infrastructure is a major game changer for the region because this road would connect to points west and would lead to the nation’s commercial capital, Managua. The same potential applies to moving export goods to the port from the remainder of the Atlantic coast. For the Atlantic region, benefits such as electric generation and supply to the grid are possible as well as thousands of permanent jobs which support canal activity. Fuel-storage capacity and, potentially, a refinery would be built, further adding to supply chain enhancements for a variety of industries in the region. Tens of thousands of temporary jobs would be created during the 5-year construction period. Half of these jobs are guaranteed to go to local workers. HKND Group has direct access to information pertaining to job creation and infrastructural development. Engineers and financial specialists work directly for the firm and liaise with both the Nicaraguan government and international organizations which will be involved with the project.

Lyngby (2008) studied the rural Nicaraguan road network to determine the social and economic behaviors associated with the system. She found that most rural Nicaraguans still live over 50 kilometers from the nearest primary road and that the access issue is particularly acute in the Atlantic-coast region. In the west, there are roughly 10,000 kilometers of primary and secondary road, but the Caribbean coast primarily uses local tertiary-road and navigable brown-water networks to access commercial centers. The study found that, between 1998 and 2005, although there was no significant road construction, transportation patterns began to change;

major growth with paved-road use was observed. The study included the rainy season which has a propensity to wipe out poorly constructed roads. In the areas where paved-road use increased, there was a clear correlation with increased household incomes. A majority of the data characteristics used by Lyngby were derived from household-survey data collected by the Nicaraguan government using World Bank Living Standard Measurements.

Pang (2015), of the HKND Group, took Lyngby's (2008) work a step further. In addition to a highway system in the Atlantic region that will facilitate construction of the canal project, economic improvements are likely to occur. These infrastructure enhancements include, but are not limited to, both temporary and permanent job opportunities where higher household incomes will result in more disposable income; including establishing new export opportunities in the region. Also, the canal will assist with regional reforestation because improved economic conditions will help end illegal logging practices. According to the HKND Group, the canal will improve the area's environment and promote eco-tourism. Lastly, new foreign trading zones will be established so that local goods and agricultural products can be accessible to North, Central, and South American markets. Pang used data provided by Nicaraguan government personnel and analysis from employees at the HKND Group to determine the project's economic influence.

With new roads and an appetite for roughly a million gallons of fuel per day for construction, additional infrastructure will be required to meet the demands. Witte-Lebhar (2012) critically analyzed the joint Nicaraguan-Venezuelan plan to build the Supreme Dream of Bolivar refinery and storage complex in western Nicaragua. This $6.6 billion project seemed very possible when oil had a good priced and the Venezuelan economy was flush with cash; however, at the time of this writing, prices are subdued, and economic/political instability has drastically reduced the likelihood of this project. Should the canal come to fruition, it is likely that, given the fuel demand for both the project and the economic activity thereafter, additional investments will occur on both coasts. To transport fuel, it will be necessary to expand the Atlantic coast's primary and secondary roads. A majority of Witte-Lebhar's analysis was derived from Nicaraguan and Venezuelan government plans to facilitate this project. Because the data were relatively opaque, it is difficult to determine how accurate the estimates and respective economic-impact forecasts are.

2.3.6. Supply Chain Improvements

The construction of the Nicaragua canal presents a number of supply chain improvements for the nation, especially in the Atlantic region. Van Der Vorst et al. (2007) indicate that developing-world supermarkets import roughly 30% of their agricultural products. With new infrastructure and supply routes, Nicaragua could benefit from developing traditional supply chain network components. For example, producers are plentiful in the Atlantic region; however, processors and distributors are non-existent. As such, the producer to retailer model is impractical due to transportation shortcomings and no supply chain network. If the canal came online along with investment, traditional networks could develop. Inputs would become available; producers would send their products to processors; and then, the processors would use distributors to ship goods to retailers in the nation's western areas. Consumers could then become much less reliant on expensive imports.

Constructing interoceanic canal projects has a number of highly beneficial effects on supply chains as well as national and regional economic systems. Kertledge (2015) studied the economic and supply chain effect that resulted from constructing the Panama Canal and then predicted how a Nicaraguan project would transform the economy. For Panama, immediate and direct economic benefits were realized. There were thousands of people employed in construction, and the multiplier effect of dollars spent in the region was immediately felt. Indirect benefits were also realized as ship crews and the presence of the U.S. military created local economic growth that became the envy of Latin America. Throughout the second half of the 20th century, rent paid by the United States to the Panamanian government enabled investments in domestic infrastructure and education. Following the transition to the Panamanian government, investments in roads and bridges coupled with the enlarged free-trade zones positively affected supply chains for several domestic industries.

Nicaragua stands to gain similar benefits according to Kertledge (2015), albeit with Chinese assistance versus American help. Given the soil's fertility, the percentage of the labor force employed by the agricultural and service sectors, and the need for basic infrastructure investments, the nation, especially the Atlantic coast, will experience a transformation. Investments in western Nicaragua's refining capacity and storage facilities for refined fuel in the Atlantic region will help to reduce the constant trade deficit. An overreliance on industrial commodities and energy from foreign markets has placed Nicaragua in a tight economic position. Building the canal will alleviate many economic constraints, and with transportation and logistics improvements, we will likely observe immediate growth and development. For example, regional value chains, e.g. the maquila garment industry, will see tremendous benefit as Nicaragua maintains a significant competitive advantage due to low labor expenses. Given that Asian production prices have risen, the expansion of free-trade zones would likely inspire more foreign investment for supply chain growth in the garment and similar industries.

In addition to contributions to the global supply chain and domestic markets, there is major potential for regional job creation as a direct result of canal construction. In an analysis conducted by O. Sanchez (2012), the Panama Canal created millions of jobs since its inception.

For example, almost two million jobs were generated within the Zona Libre (free-trade zone) de Colon. Over one million operational positions in the ports and along the canal were created. Tens of thousands of positions related to multimodal transportation, railway construction, legal services, and maritime repair came to fruition. There is real potential for Nicaragua to realize similar benefits as a result of its maritime and land-based expansion. O. Sanchez used dozens of local interviews to frame his analysis; many of them were anonymous because people feared reprisal from their employers. Overall, a new canal will introduce a number of opportunities for the region to realize global supply chain integration.

Several technical analyses of supply chains in the region have been accomplished by governments and NGOs. The World Bank (2012a), in its agro-logistics research, has identified a number of the region's supply chain bottlenecks that would be mitigated by constructing the canal. First, logistics bottlenecks in Central America have led to expenses that are double what they should be. Beef exports in Nicaragua, for example, are twice (sometimes three times) as costly due to poor roads and an export environment that would benefit from a free-trade zone. A positive consequence of the canal would be not only improvements to rural roads, but also several free-trade zones in both the eastern and western regions. A complete overhaul of customs regulations would likely result from establishing free-trade zones, thereby changing antiquated and supply chain-inhibiting regulations. New roads and export opportunities could also lead to a refreshed transportation regulations. This improvement could reduce wait times and expenses at weigh stations and through other checkpoints. Time delays due to poor road conditions and export challenges can sometimes lead to the total loss of fresh products that require time-sensitive delivery.

Updated roads, modern regulations, and access to more markets as a result of free-trade zones, along with the canal, could lead to a complete transformation of the agricultural and manufacturing distribution networks. Investments in refrigerated storage facilities, processing and distribution capacity, and improved warehousing could come to fruition. The World Bank (2012a) used both quantitative and qualitative data collected in the country along with an analysis of the nation's legislative and regulatory environment. A streamlined regulatory environment, an improved transportation network, and new land which would likely be available for cattle ranching due to land-use changes will lead to significant growth in Nicaraguan beef production (World Bank, 2012a).

The United States Agency for International Development (USAID, 2004) researched Nicaragua's supply chain capacity, and unfortunately, investing in the Atlantic region has not changed remarkably since the research was conducted. According to the study, not only is the road network non-existent, but the current port capacity is also minimal and does not contribute a significant amount of goods and products to the Caribbean or Miami, a port known as the recipient of most goods from Latin America. In terms of importing, most bulk goods are either flown into the region or are extremely expensive due to port fees and customs expenses. As a result of the inadequate infrastructure which includes no railroad system, customs and brokerage services are sparsely available in the Atlantic region due to the lack of demand. Warehousing appears to experience similar challenges. With the canal's development, many of these missing links in a traditional transnational supply chain, especially ones that resemble other Latin-American practices, would be developed due to a supply chain for goods and some services as well as a demand for export.

Modern logistic networks are built using just-in-time models to include the use of international shipping companies, but given the inaccessibility of infrastructure to support this model, only a project as large as a canal can propel the Atlantic region 50 years forward and transform the area’s ability to export. From a modern supply chain perspective, it would be entirely possible to mitigate a majority of the challenges highlighted in the USAID (2004) study. Cost advantages for exporters would appear and reduce inventory costs; speed for cargo delivery would improve; and new maritime/land supply routes would become available as a result of the megaproject. The USAID study utilizes data collected from a team stationed in Nicaragua as well as available supply chain data for Nicaraguan products.

The same pattern applies to industries that have global supply networks. According to Nicita, A., Ognivtsev, V., & Shirotori, M. (2013), the emergence of local economic sectors, such as producing garments in a free-trade zone, would produce a comparative advantage for the developing world. For example, relocating production process to different countries, in this dissertation’s case, from Asia to Central America, would enable transnational companies to take advantage of the best-available labor or natural resources. At the same time, this workforce would enable global firms to maintain their competitiveness and to augment productivity while minimizing overall expenses.

Eastern Nicaragua can modernize using globally successful models. Constructing the Nicaragua canal has the ability to not only influence global transportation patterns, but also to modernize the nation of Nicaragua. With new infrastructure and opportunities, this small Central American nation is at the cusp of realizing its true economic potential as a result of new domestic transportation networks and integration into global supply chains which are currently unattainable. After transitioning to Panama, the Panama Canal has become a major funding source for infrastructure projects throughout the nation Sanchez, O. (2012). In addition, tens of thousands of people are employed via supporting industries. This direct economic effect has led to the creation of unique free-trade zones and global economic integration.

Consider the long-term benefits realized in Egypt and Panama as a result of canal construction and control. In 1956, the Suez Canal was officially transferred to the Egyptian government. For almost 20 years, regional instability and conflict prevented the canal from realizing its full economic potential, but once stability returned, Egypt began to experience increased foreign investment and a sizeable reduction in unemployment as direct and indirect results, respectively, of the canal. The Suez Canal is responsible for 10% of Egyptian GDP, and after government employment and tourism, the canal is the third-largest sector of the economy. In a desire to jumpstart an ailing economy, the Egyptian government announced and executed a canal expansion project in 2014. Kenawy (2016) estimated that unemployment would decrease due to new domestic transportation-infrastructure investments along with industrial growth in areas such as agricultural exports, textiles, and mining. Moreover, increased direct foreign investment is likely in these industries due to new transportation capacity and the ability to move goods to market via networks which lead to the canal. The Egyptian Pound will also benefit due to transactions in local currency, potentially strengthening domestic economic sectors.

Another sea-level waterway that has provided an amazing benefit to its host is the Panama Canal. In 2007, the Panama Canal began a massive expansion to ensure that over 90% of the world's cargo vessels could traverse it. According to *The Economist* ("The Panama Canal," 2009), by 2025, transfers from the Canal Authority to the Panamanian government could exceed $4 billion per year. In addition, some economists believe that direct and indirect economic effects on Panamanian GDP from the canal are as high as 30%! This growth is due to the development of several free-trade zones as well as building roads which connect labor pools from cities to free-trade areas and, subsequently, to port. Since transferring the authority from the United States to Panama, the central government in Panama City has been able to make significant investments in areas such as road construction and education in order to create better living conditions for the citizens.

CHAPTER 3. METHODOLOGY

3.1. Introduction

This research concentrates on how to minimize transportation costs for eastern-Nicaraguan communities in order to meet the regional growth needs associated with a network that enables global supply chain integration. It is important to note that a transportation network could be constructed as part of economic-modernization efforts; as such, a canal is not a required catalyst for transportation and logistics planning. Because the new network will encourage land-use policy modernization, increased export opportunities for both livestock and crops, and the potential development of light manufacturing capacity, Bluefields will likely remain the critical transportation hub as well as the region's economic center for the next several generations. The research focuses on developing a transportation model that minimizes costs while enabling economic development and societal benefits as well as offering logistics improvement opportunities for industries which have traditionally not had access to global supply chains. The study also examines the costs to develop transportation infrastructure using Bluefields as the critical node, Punta Aguila as the deep-water port for export, and the various transport infrastructure options based on the requirements and available resources.

Without a canal, there is still undeveloped potential. If the transportation-modernization effort occurred, the network would likely look different because Bluefields may not be the central node; however, the Inter-American Development Bank is currently engaged in constructing a road from Bluefields to Nueva Guinea, resulting in a greater likelihood that Bluefields will be the node (Inter-American Development Bank, 2014). As of early 2019, it is unlikely that construction would occur as expeditiously as a scenario involving the building of the Nicaragua canal. This lack of progress is due to inadequate resource availability as well as political support. This project focuses on the economic outputs and societal benefits created by the new infrastructure.

3.2. Research Questions

The proposed canal project would have the potential to completely transform the Nicaraguan economy. In order to accomplish this transformation, there are transportation-infrastructure requirements necessary to facilitate the new economic model. With new transportation capacity, logistical models will be developed to support the nation's contribution to global supply chains in various industries. As such, there are a number of research questions which will be addressed in this study, including, but not limited to,

1. What is the minimum cost of developing a multimodal transportation network in the RAAS and RAAN which will enable the movement of goods and services while optimizing full economic and societal potential?
    a. What will minimum costs be for various transportation options in the region?
    b. What triggers will determine if rail should be built in areas versus 10-ton road infrastructure with an emphasis on Bluefields to Punta Aguila?
    c. What triggers will determine if river transportation should be expanded versus a 10-ton road infrastructure with an emphasis on interior rural communities?
    d. What triggers will determine if fishing boats on the Caribbean coast should have additional investment versus more road infrastructure in order to move seafood to Bluefields for consumption and processing for export?
2. What are the long-term transportation requirements which are necessary to enable communities throughout the autonomous political departments to realize their full economic potential?

3. What potential contributions to global markets and supply chains will this network enable by using the existing economic activity as a baseline for growth?
4. What will be the long-term transportation costs to support the creation of Bluefields as the critical node for transportation? In order to determine the cost, the following arcs will be assessed using highway, rail, sea, or brown-water transportation options to connect with Bluefields.
    a. Bocana de Paiwas (small community primarily focused on agricultural production)
    b. Corn Islands (small community primarily focused on the tourism industry)
    c. Desenbocadura de la Cruz de Rio Grande (small community primarily focused on agricultural production)
    d. El Ayote (small community primarily focused on agricultural production)
    e. El Rama (medium-sized municipality known as the area where the roads from Managua end and the river-transportation system begins in the South Caribbean Coast Autonomous Region/primarily a regional trading zone with a large agriculture potential)
    f. El Toruguero (medium-sized municipality primarily focused on agricultural production)
    g. Kukra Hill (small community primarily focused on agricultural production)
    h. La Cruz de Rio Grande (medium-sized municipality primarily focused on agricultural production)
    i. Muelle de los Bueye (small community primarily focused on agricultural production)

    j. Nueva Guinea (medium-sized municipality primarily focused on crop production and livestock/close to the large city of Leon and will likely benefit less than communities further east due to its proximity to Nicaraguan population centers. There is the potential, however, for a large expansion of beef exports.)
    k. Pearl Lagoon (small community primarily focused on tourism)
5. What will a RAAN transportation equivalent look like with respect to transportation-infrastructure development and regional-network integration?
6. Although the southern region of the autonomous political departments will realize a majority of the economic benefit, the North Caribbean Autonomous Region will also encounter new export opportunities as a result of transportation-infrastructure development, increased logistical capacity, and overall global supply chain integration for its economic sectors. Unlike the major disconnections in the RAAS, communities in the north are primarily connected by road and the capital, Puerto Cabezas; however, we want to know the costs to develop highway, rail, or brown-water transportation options for travel to Bluefield given its future status as a regional transport node with a major deep-water port directly to the south.
    a. Bonanza (medium-sized municipality focused on mining)
    b. Prinzapolka (medium-sized municipality focused on tourism and some agriculture)
    c. Puerto Cabezas (regional capital, likely the location where a road to Bluefields will originate/economic focus on tourism, agriculture, and trade)
    d. Rosita (small community focused on mining)
    e. Siuna (medium-sized municipality focused on agriculture)

f. Waslala (medium-sized municipality focused on agriculture)
g. Waspam (border community with Honduras/primarily focused on auriferous mining and trade given its status as a medium-sized international crossing)
h. Mulukuku (small community primarily focused on agriculture)

7. What exogenous factors may influence building the network? This research examines the following scenarios.
    a. How would changes in commodity prices affect the network?
    b. Would the network expense still be justified if there were no canal?
    c. Which alternative-production scenarios exist, and how might these scenarios influence the network?
8. Will a modern network reduce the logistics “tax” placed on small transportation companies and farms due older assets and poorly maintained and unpaved roads?

3.3. Study Area

3.3.1. Land-Use Change

Land-use changes should be expected if the anticipated transportation investments occur. The changes are due to new transportation patterns as well as expanded economic opportunities. If one were to examine nations with similar soil types, climate, socioeconomic situations for farmers, and historic parallels, it would be fair to assume that some level of deforestation, followed by expanded cattle operations and crop cultivation, will occur; this situation is precisely what happened in Brazil’s Amazon region and parts of Belize following major transportation upgrades and access to markets (Andersen et al., 2002). However, it is important to note that the Norwegian Agency for Development Cooperation has been educating and training farmers in RAAN and RAAS regions to utilize existing vegetation in order to maximize its potential without degrading the environment. The initiative focused primarily on agroforestry and crops that would sustain the local population. This project, funded by the Norwegians but implemented by the Foundation for the Autonomy and Development of the Atlantic Coast of Nicaragua (FADCANIC), demonstrated that many farms have expanded the cultivation of crops such as plantains, cocoa, fruit trees, coconut, and pejibye palm (Guharay, 2007). The research also found that many farms had cattle and pasture operations at the expense of local forests. The lessons learned from nations with similar climatic and economic situations prior to the introduction of modern transportation modes are critical to ensuring that Nicaragua develops responsibly by using methods that are mostly sustainable. It is assumed that significant deforestation will occur, however, to increase both crop and livestock opportunities.

With respect to the tropical lowlands on the Caribbean, soils in the RAAN and RAAS regions are highly weathered with low pH and nutrient reserves (Margenot, 2016); although some microclimates offer rich soil. Given the high amounts of precipitation and the soil type, deforestation followed by using the top soil becomes an easy and short-term application of crop cultivation. Without the forest’s deep roots, each crop cycle reduces the nutrients required for maximum soil use. To avoid this short-term approach for improving the local economic situation, agroforestry will continue to be the preferred method of crop development in the region. Margenot recommends that cacao, pineapples, and coconut be harvested as a sustainable source for the cash crops sold in domestic and international markets. In addition, locals should continue to grow breadfruit in order to feed their families; this item has been a staple in the Moskito coast diet for hundreds of years. These crops are sustainable, reduce the propensity for deforestation, and limit the land-use changes that enable cattle and grazing to drastically change the landscape. It will be critical for the government to educate the public about the profit potential associated with these products because enforcing deforestation is very difficult. In addition, the Center for Export and Investment Nicaragua will have an opportunity to promote local products once transportation options become available to move crops to market.

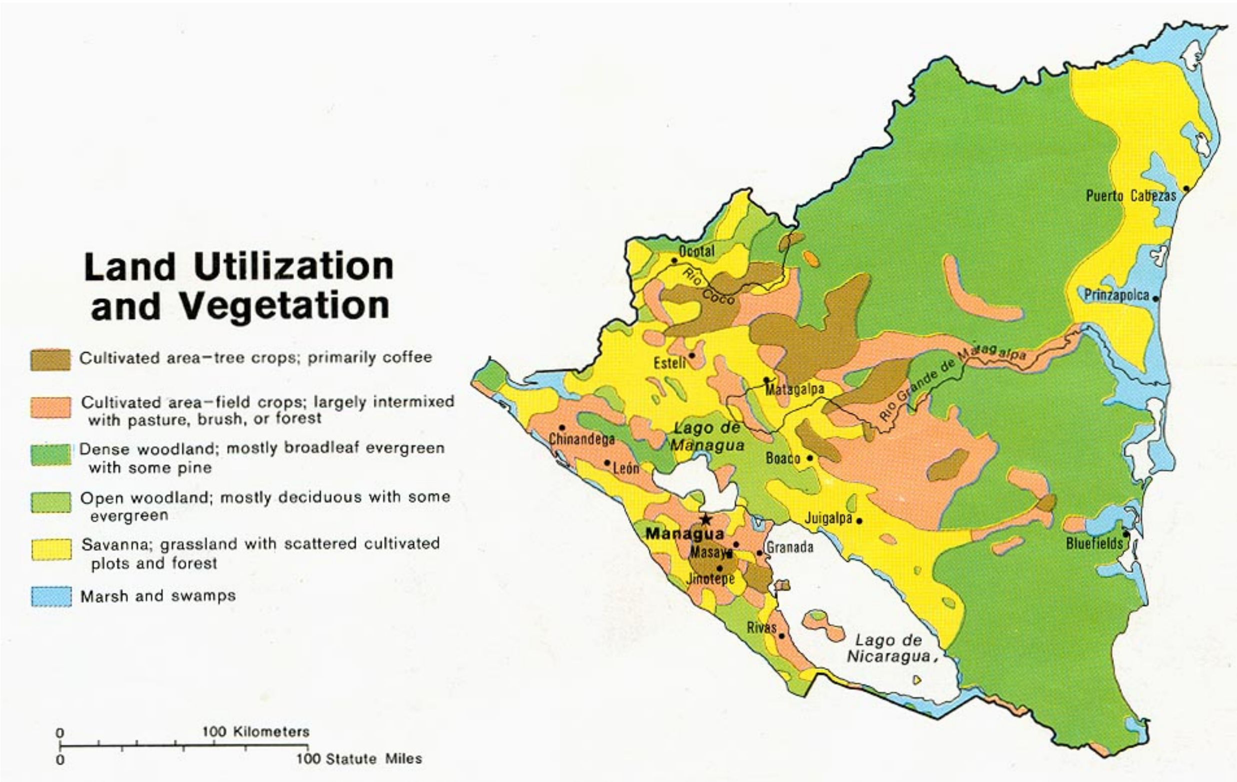

Figure 4. Land-use map of Nicaragua (Perry-Castenada Map Collection,1997).

3.3.2. Economic Activity

3.3.2.1. Crops

Nicaragua is the second-poorest country in Latin America, following Haiti, and is highly dependent on agriculture; approximately 20% of the GDP is generated via farming, and roughly one-third of Nicaraguans earn their livelihood from farming (Margenot, 2016). As such, introducing new transportation opportunities presents both opportunities for societal and economic growth as well as challenges for the government to ensure that land use is sustainable. In Nicaragua, small and medium farms produce 90% of the crops. This approach is a departure from the trend of larger corporations consolidating large swaths of land and creating megafarms which export throughout the world. According to the Center for Export and Investment (CEI) Nicaragua (2017), the nation is split into three soil macro regions. The Pacific region is considered to be the best for soil types which are conducive for cash crops; the central region's main focus is on cattle along with some coffee and tobacco production; and the eastern region, the area which would benefit most from transportation investments, has fishing and the commercialization of forests as the best agricultural opportunities in addition to cattle ranching.

3.3.2.2. Forestry

As land-use changes occur as a result of transportation and infrastructure investments, Nicaragua has an opportunity to responsibly harvest its forestry products in order to avoid mistakes which were made in Brazil's Amazon region. Nicaragua must be able to balance environmental conservation with exporting quality wood. There will be environmental degradation based on regional trends following land development; however, Nicaragua can implement and enforce commercial management plans to avoid major destruction. In addition, central- and eastern-Nicaraguan farmers are primarily dependent on livestock. Over the last several decades, cattle farming, including beef exports, has grown significantly. As a result, this profitable trend, coupled with the demand for forestry products, may lead ineffectively monitored land-use adjustments.

3.3.2.3. Livestock

New transportation options are likely to have a major positive influence on the region and its main exports. For example, livestock farming and the fishing sectors have enjoyed growth in recent decades, but have been limited due to poor logistics and transportation networks. For example, beef processing in safe and certified facilities is lacking; the same capability applies to flash-freezing capacity and the ability to move larger amounts of seafood to markets. Therefore, growth for these industries will remained checked until additional capacity is developed for transporting and for processing and moving products both domestically and internationally.

According to the Nicaraguan central government, the nation's cattle industry is quite robust; after domestic consumption, Nicaragua exports the most beef in Central America, making it the nation's second-largest export following coffee (*Secreteria de Integracion Economica* Centroamericana, 2018). Several hundred million dollars of beef per year are exported from Nicaragua, making cattle highly lucrative for ranching firms of all sizes. In addition, 95% of the cattle farms are dual purpose, providing both fresh milk and beef to customers throughout the country (Cajina, 2013). A majority of Nicaragua's cattle herd is located on ranches in the humid central part of the nation, making the RAAN and RAAS regions the country's largest producers (almost 40%) of beef (Cajina, 2013). As such, milk production is very high in the autonomous regions; however, transportation limitations, combined with the lack of refrigeration capacity, have led to limited export (both domestic and international) opportunities. In total, only 30-40% of the produced milk can be transported to collection centers due to infrastructure obstacles (Cajina, 2013).

3.3.2.4. Seafood

Shrimp farming and fishing are also major employment sectors for Nicaraguans who live along the Atlantic and Pacific coasts. Shrimp farming accounts for 41% of all seafood exports; 80% of these exports are purchased by consumers in the United States (Food and Agriculture Organization of the United Nations [FAO], 2017a) In the 1990s, commercial seafood packing plants along the Atlantic coast were privatized, leading to double-digit growth year after year. With additional export avenues and potential, this industry could grow substantially given the potential global investment. Since 2000, marine-fishery employment has more than doubled

(Food and Agriculture Organization of the United Nations [FAO], 2017a), creating over 45,000 jobs for Nicaraguans; a large portion of these fisheries are on the Atlantic coast. Total aquaculture production has tripled since 2000 as well with the large growth in shrimp and lobster fishing (Food and Agriculture Organization of the United Nations [FAO], 2017a . The Food and Agricultural Organization of the United Nations, in close collaboration with the Nicaraguan government, believes that growth in this sector shows even greater potential.

Like livestock and cash crops, there is the potential for fisheries and seafood production to increase as a result of new transportation modes and enhanced logistic networks. Presently, Nicaragua exports more than $100 million in seafood; this number does not include domestic consumption. As such, new infrastructure could inspire foreign direct investment into processing capacity, including packing plants. With low taxes, an abundance of seafood, and an internationally renowned reputation for clean seafood exports, there is potential for this sector to double over the next 10 years as it did since 2000. Therefore, both the RAAN and RAAS regions stand to gain immensely from enhanced global supply chain integration along with increased domestic consumption of aquaculture products whether the items are harvested from the sea or from fisheries.

3.3.2.5. Manufacturing

At the time of this writing, very little manufacturing activity exists in eastern Nicaragua due to poor infrastructure, an ill-trained workforce, inadequate private capital to enlarge facilities and projects, and very little foreign direct investment. With the introduction of a regional transportation network as well as the products which are likely going to be exported from the region, Bluefields will enjoy substantial growth potential independent of the canal infrastructure.

3.3.2.6. Other Activity without an Immediate Impact on Transport

3.3.2.6.1. Facility Needs

To facilitate major growth, new manufacturing opportunities, slaughter houses, distribution centers, free-trade-zone infrastructure, and service, support buildings, such as hotels and restaurants, will be constructed to meet the demands of a rapidly modernizing economy. Having a new transportation network in place as a result of economic growth and expansion will necessitate facility construction based on the demand. For example, along the highway routes, food places, lodging, and gas stations will be built. A free-trade zone will encourage facility construction for places to store raw materials, for manufacturing sites, and for warehousing capacity to ship imported and exported products (Autoridad del Canal del Panama, 2016). An anticipated expansion of both the cattle and fishing industries will create new meat- and seafood-processing facilities along with the requisite infrastructure required to store the ready-for-export or domestic-distribution product. This section is difficult to quantify, so historic trends for these industries, current production, and forecasted capacity/trajectories will be utilized to determine each industry's growth.

3.3.2.6.2. Service Jobs

In addition to major agriculture and manufacturing activities that influence the region's total freight movement, there are secondary and tertiary industries which will add to the major contributors to tonnage. These industries include, but are not limited to, ones that directly and indirectly service canal construction and new industrial growth. Industry may also surface as a response to improved household finances given new opportunities for primary sector products.

Data concerning restaurants per capita are difficult to ascertain for nations in Central America. Developed nations offer data pertaining to full-service restaurants per capita, and so does every state in the United States. Given that new international workers and domestic migration will likely occur based on additional opportunities, an assumption that several thousand restaurant jobs will be made to meet worker and resident requirements. This assumption is based on new income potential and the region's projected activity; consider the new trade zones and shipping jobs that occurred as a result of the Suez and Panama Canals.

There are other sectors within the hospitality industry that should also be considered within this variable. Requirements for new industries' laundry services, coupled with lodging needs, should be captured. Like the data concerning restaurants per capita, ascertaining the baseline necessity for these services is difficult; however, given the volume of new workers supporting the canal operations, the industrial and agricultural growth, the export services, and additional tourism, it is safe to assume that, in the long term, thousands of jobs will be created. When there are sources of economic growth and development, secondary and indirect benefits reveal themselves quickly; take for example boomtowns in the American West along with community development in Panama during and following the canal's construction.

Other positions that may be created as a result of construction include gas stations, fuel refineries, new supermarkets which include meat and crops which are harvested locally, an expanded airport in Bluefields, new tourism offices, and additional opportunities. Given this level of economic activity, additional freight movement requirements could occur when moving goods throughout the region in order to facilitate the new economic-growth activities.

3.3.3. Unintended Consequences

With growth, expansion, and environmental alterations will likely come unintended consequences. With respect to positive outcomes, many scenarios were captured in the economic- and community-development growth prospects. For example, new facility construction had a variety of estimates based on a number of scenarios associated with the economic development of a highly impoverished nation with so many natural resources. This impact is in addition to the effect associated with new economic opportunities that result from transportation-network expansion. To ensure that negative unintended consequences are mitigated, each factor of economic development that will affect freight amounts will be limited to capacity constraints of no greater than 50% land-use change.

In addition to the positive outcomes associated with constructing the canal and the additional transportation and logistical infrastructure, there is a likelihood that some unintended consequences will occur as a result of the rapid adjustment. For example, given how many rivers run through the RAAN and RAAS regions, it is likely that deforestation, coupled with soil degradation, may lead to increased flooding. An environment that was previously able to absorb large fluctuations in precipitation from tropical systems may not be able to accommodate this new setup. To avoid major public expenses, a 50% or less land-use change will ensure that major disasters are abated. In addition, road infrastructure that includes drainage, such as curbs and gutters, or culverts and ditches, may divert heavy rains from areas which cannot absorb an intense increase of rain. Some industries may be negatively affected by the canal and the road infrastructure. For example, an area may be overfished as a result of the new flash-freeze capacity, storage, and export opportunities. Put simply, we do not know what we do not know. We can follow other nations with similar transitions and ascertain the societal costs associated with this transformation, but resource constraints, culture, climate change, and other factors may lead to poor long-term decision making and expensive choices. This study attempts to maximize societal benefits because it quantifies the minimum costs to develop a new transportation network.

3.3.3.1. Municipalities within the RAAN and RAAS

The RAAN and RAAS regions contain a number of municipalities, and each would have a town center with aa municipal office, or *cabildo*. Many of these communities have inadequate transportation infrastructure to facilitate economic growth and development; however, there are some communities that enjoy varying transportation options, ranging from dirt roads to paved roads. Therefore, it is important to introduce each municipality and to discuss both economic activity and existing transportation opportunities.

3.3.3.1.1. RAAS

3.3.3.1.1.1. Bocana De Paiwas

Bocana de Paiwas is connected to Managua via Highway 21. It is a municipality with a population slightly over 30,000 and is heavily dependent on cattle ranching. Operations are likely to grow if the international consumption of Nicaraguan beef continues to increase. Bocana de Paiwas is located on the periphery of the RAAS region's savanna and forest, and is only about 5 hours from the capital.

Given the growth of cattle ranching over the last several decades, additional economic activity in the region, coupled with a higher disposable income, will assist Bocana de Paiwas with its desire to increase its beef production. New investments in regional-transportation infrastructure will create a logistics capacity that did not exist previously, leading to an opportunity for increased timber harvesting because of access to international supply chains.

3.3.3.1.1.2. Corn Islands

The Corn Islands are one of the largest tourist attractions in Nicaragua. East of Bluefields, this area is developed to include modern amenities and a resort environment that has enabled the region's growth and development. With additional mainland infrastructure, tourism to the islands may increase along with job opportunities for a growing service industry.

3.3.3.1.1.3. Desembocadura De La Cruz De Rio Grande

Desembocadura de la Cruz de Rio Grande is a small community which is primarily focused on fishing and agricultural production; its population of mostly Miskito Indians totals about 4,000. Within this municipality, there are several small towns along the coast and along the Rio Grande de Matagalpa. Given that there is the potential for Nicaragua's fishing industry to grow, a road to Kukrahill, which also serves several small communities along the route, would be highly beneficial for fisherman and small-crop producers who utilize the tropical forest to process cash crops.

3.3.3.1.1.4. El Ayote

El Ayote is connected to Managua via Highway 7. It is a municipality with a population slightly over 12,000 and is heavily dependent on cattle ranching, although there are some small-scale bean farms. Operations are likely to grow if international consumption of Nicaraguan beef continues to increase with lower transportation costs. Like Boacana de Paiwas, El Ayote is located on the periphery of the savanna and the RAAS forest, and is only about 5 hours from the capital.

3.3.3.1.1.5. El Rama

El Rama is a medium-sized city of approximately 53,000 people and is known as the area where the roads from Managua end and the river-transportation system begins in the South Caribbean Coast Autonomous Region. El Rama is primarily a regional trading zone with large agriculture potential. It is anticipated that both cash crops and ranching will grow should the canal come to fruition. Unfortunately, El Rama is likely to be in the center of the area that will be affected by deforestation. This elevated deforestation rate is a result of the existing trade infrastructure for cattle ranching, goods, and services along with a desire to grow the region's exports.

3.3.3.1.1.6. El Toruguero

El Toruguero is connected to El Rama via dirt roads. It is estimated that traveling between them takes approximately 1-2 hours via the existing road. This municipality has a population of approximately 20,000 people who depend, primarily, on cattle ranching. There is also water transport via Rio Kukarawala which connects to larger rivers. Eastern Nicaragua has dozens of rivers which total several hundred miles; historically, the half a million residents in and along Nicaragua's river system have used brown-water travel to facilitate trade. The issue with this travel method is that it is slower than road travel and can only be facilitated during the wet months.

3.3.3.1.1.7. Kukra Hill

Kukra Hill will benefit greatly from improved infrastructure. Although the municipality only has 9,000 inhabitants, it has a number of economic activities that are suited for growth and expansion. Presently, cattle ranching is the major economic driver in the municipality; however, Kukra Hill is known to have the most fertile soils in the region (Perry-Castenada Map Collection, 1997). As discussed later in this model, the soil contains a great deal of clay and silt due to its proximity to the Caribbean Sea; however, people can grow a number of crops to sustain coastal diets and should consider exporting cash crops. In addition, given the area's proximity to the Atlantic Ocean, fishing plays a major role in the region.

3.3.3.1.1.8. La Cruz De Rio Grande

La Cruz de Rio Grande is a municipality of approximately 23,000 residents who depend on 3 economic sectors: small and medium-sized ranching operations, the growth and sale of cash crops, and river trade. The community gets its name from the nation’s second-largest river, Rio Grande de Matagalpa. Like many of the communities analyzed for economic growth and development as part of this dissertation, the expansion of cattle ranching and beef sales, coupled with improved cash-crop production, is likely based on existing livelihoods, the area’s history, and the ability to leverage and increase the prevailing infrastructure in order to integrate into regional logistical networks and global supply chains.

3.3.3.1.1.9. Muelle De Los Bueye

Muelle de los Bueye is connected to Managua via Highway 7. It is a municipality with a population slightly over 3,000 and is heavily dependent on cattle ranching and, presumably, small-scale farms which grow a variety of crops. Operations are likely to increase if international consumption of Nicaraguan beef continues to go up, given the climate and the existing cattle-industry infrastructure. Like several communities on the western edge of the RAAS region, there are no transportation improvements suggested as this time.

3.3.3.1.1.10. Nueva Guinea

Nueva Guinea is very unique in that it is barely located in the autonomous region and is very close to one of Nicaragua’s largest cities, Leon. As a result, this community of almost 70,000 is connected to the nation via several highways. Like the other communities in the region, most commercial activity is centered around cash crops and beef production. Given its proximity to highway networks and the jungle to the east, it is likely that large ranching activity could occur in this area. Authorities are already concerned about the potential for deforestation in the area and continue to acknowledge that this issue has accelerated.

3.3.3.1.1.11. Pearl Lagoon

Pearl Lagoon is a community of approximately 11,000 inhabitants on the Caribbean coast. Until 2006, it was only accessible to Bluefields via boat; however, investment for a gravel and dirt road connected the community to Kukrahill in 2006. For now, this connection suffices; however, two industries are likely to be affected by regional growth and development. The fishing industry will likely grow. Full economic- and community-development potential will also be driven by tourism. Pearl Lagoon has several hotels, restaurants, and eco tours that cater to tourists. Having a suitable road will enable more tourists to explore the area. Additional development may result in more tourism coming from the nearby Corn Islands as well. Combined, commercial fishing and tourism will likely assist the area with modernizing.

3.3.3.1.2. RAAN

Although the southern region of the autonomous political departments will realize a majority of the economic benefit, the North Caribbean Autonomous Region will also encounter new export opportunities as a result of transportation-infrastructure development, increased logistical capacity, and overall global supply chain integration for its economic sectors. Communities in the north are primarily connected by road and the RAAN capital, Puerto Cabezas; however, we want to know the costs to develop highway, rail, or brown-water transportation options for travel to Bluefields given the assumption that Bluefields is the critical node within the network:

3.3.3.1.2.1. Bonanza

Bonanza is a medium-sized community located approximately 60 miles inland and almost due west of Puerto Cabezas, the RAAN capital. Due to its proximity to mines, Bonanzalikely draws a majority of its economic activity from mining (Elizondo, 2015). There are small farms and very few non-mining exports in the area; cattle ranching is not prevalent. As a result, the community is built almost exclusively on its mining industry and the secondary economic activity associated with serving miners, e.g., hotels and restaurants. If the area were to grow its agricultural industry, companies could export material via Nicaragua Highway 30 which offers a direct line to the provincial capital. It takes approximately 5 hours to reach Puerto Cabezas by car.

3.3.3.1.2.2. Mulukuku

Mulukuku is a municipality of approximately 35,000 people which is located between Puerto Cabezas and Managua. It is known for extensive cattle farms and large operations that support both beef production and large-scale milk exports. Given its proximity to Managua and its location along the 21B Highway, much of the milk is exported in tanks to be pasteurized. This area could be affected by additional deforestation because it is likely that the beef and milk export demand could increase production pressures. In addition, large-scale farming operations could expand by utilizing the existing logistics networks.

3.3.3.1.2.3. Prinzapolka

Prinzapolka is a municipality located due south of Puerto Cabezas. Although it is only 30 miles or so south of the provincial capital, no roads serve this municipality of approximately 17,000 residents. Like many communities located in the RAAN and RAAS regions, Prinzapolka has access to immense and valuable natural resources. The community is situated on the

Caribbean coast where there is access to bountiful fishing grounds. Shrimp, lobster, and various species of fish feed a majority of the region's residents; in addition, there is the potential to advance the area, enabling the growth and associated requirements for fishing-industry development. If there were a logistics network in place, this area would have little problem finding foreign investment to establish exports given the quality of its seafood.

3.3.3.1.2.4. Puerto Cabezas

Puerto Cabezas is a city of approximately 70,000 and is RAAN's regional capital. Like other larger cities in the RAAN and RAAS regions, it has the potential to grow as a result of new transportation infrastructure, access to modern logistics networks, and integration with the overall supply chain. Like other coastal communities, fishing is an important economic activity which should be expected to grow significantly if foreign investment were to follow. Given that this research has recommended connecting the other coastal communities with Bluefields, Puerto Cabezas would be the northernmost point of the recommended road which will connect with the new economic activity associated with the canal project.

3.3.3.1.2.5. Rosita

Like Bonanza, Rosita is a small municipality located in Nicaragua's mining triangle; it is approximately 50 miles inland, almost due west of Puerto Cabezas, the RAAN capital. It is located in the mining triangle; however, there are no active mines. If it were to enhance its agricultural industry, people could export material via Nicaragua Highway 28B which offers a direct line to the provincial capital. It takes approximately 4 hours to reach Puerto Cabezas by car.

3.3.3.1.2.6. Siuna

Siuna is a larger RAAN municipality which is located west of Rosita and south of Bonanza. The city was highly dependent on gold mining until the late 1960s when the local hydroelectric plant was damaged, creating energy shortages in the region. Crops, mostly beans, coupled with some ranching became the main economic activity following the closure of the mining operations. There are also two universities; one has an agroforestry program to assist the region with further developing micro farms. It takes approximately 6 hours to reach both Managua and Puerto Cabezas by car.

3.3.3.1.2.7. Waslala

Waslala is barely located in the autonomous region and is very close to one of Nicaragua's largest cities, Matagalpa. As a result, this community of almost 60,000 is connected to the nation via several highways. Like the region's other communities, most commercial activity is centered around cash crops and beef production. Given the city's proximity to highway networks and heavily deforested hills, cattle-ranching development has been robust.

It can be assumed that, with additional export capacity and the international price of beef, domestic supply could struggle meeting domestic demand due to overseas opportunities; it is very possible that Waslala may meet the domestic supply and demand imbalance should it become a secondary effect of new transportation, logistics, and export opportunities for both the RAAN and RAAS regions. As such, one could expect additional deforestation.

3.3.3.1.2.8. Waspam

Waspam is a border community with Honduras and is primarily focused on auriferous (gold) mining and trade. The city primarily consists of indigenous people who do not have access to many opportunities. Small-scale farming, trade, and dangerous mining activities are what the locals depend on for their livelihood. Waspam is a 4-hour drive to Puerto Cabezas via Highway 73.

3.4. Model

This study's objective is to develop an optimization model to determine the lowest-cost transportation network that will enable the growth and development of a regional supply chain for local economic drivers. The model supports multiple products using a multimodal transportation network; including the potential for intermodal development based on port investments as well as local production capacity. The model associated with this research focuses on minimizing the transportation costs required to meet the long-term public good for economic growth and development, respecting traditional land use and potential land-use changes which result from constructing the Nicaragua canal. The model will include expansion of logging, livestock, and agricultural activities; light manufacturing activities; and other economic activities. The population center which is primarily affected is Bluefields because it is the capital and regional trading center for the South Caribbean Autonomous Region. Bluefields will be the most critical node for this research given its proximity to Punta Aguila and the historic status within regional trade.

In the proposed model, we assume that there is a set of h points of origin (*cabildo*s, or centers of government in Nicaraguan municipalities) that will produce j types of freight. The freight type is based on existing and forecast economic activities once a viable logistics network is in place to facilitate product movement into domestic and global supply chains. Products throughout the network are assumed to end their journey at k; this end point is Bluefields given the assumption that a canal, as well as a deep-water port to the south, will be constructed. Each movement from point h to point k is orchestrated using i mode or transportation infrastructure type. This model concentrates on the expenses associated with various transportation options as well as the freight type and weight associated with regional output for the existing and potential industries. The model's complete notation is summarized in Table 1.

The multimodal transportation network design model includes Bluefields as the critical node based on canal-construction plans, existing infrastructure, and forecast transportation patterns. Each node in the network, a *cabildo*, or junction point where the new road will meet an existing or planned highway, will use one of four transportation modes to facilitate material flow from the points of origin to Bluefields. Mode flexibility is the basis for this research because the cost-minimization linear-programming model will determine which investments are the most efficient and cost effective, determining which transportation-infrastructure node within the network needs to be optimized in the model to meet economic-development requirements. The mathematical formulation for the transportation-network model is presented in Equation 1. below:

(Equation 1)

Min

$$\sum_{t=0}^{5} \sum_{i \in I} \sum_{(h,k) \in N} IC_i KM_{hkit}\, \beta^t + \sum_{t=5}^{50} \sum_{j \in J} \sum_{i \in I} \sum_{(h,k) \in N} C_{hkij} Y_{hkijt} \beta^t \qquad (1)$$

S.T.

$$\sum_{j \in J} \sum_{i \in I} \sum_{(h,k) \in N} Y_{hkijt} \leq S_{jh} \qquad \forall\, j \in J, \forall\, \mathrm{h} \in \mathrm{H} \in t = 6, \ldots, 50 \qquad (2)$$

$$S_{jh}\, X_{hkit} \geq Y_{hkijt} \qquad \forall\, (h,k) \in N, \forall\, i \in I, t = 1, \ldots, 5 \qquad (3)$$

$$\Sigma i \;\; X_{hki5} = 1 \qquad \forall\, (h,k) \in N \qquad (4)$$

$$\sum_{l=1}^{t} KM_{hkil} \geq D_{hki} X_{hkit} \qquad \forall\, (h,k) \in N, \forall\, i \in I, t = 1, \ldots, 5 \qquad (5)$$

$$Y_{hkit} \geq 0 \qquad \forall\, (h,k) \in N, \forall\, i \in I, t = 1, \ldots, 50 \qquad (6)$$

$$\sum_{(h,k)} \sum_{i} KM_{hkit} \leq B_{IADB} \qquad t = 1, \ldots, 5 \qquad (7)$$

$$KM_{hkit} \geq 0 \qquad \forall\, (h,k) \in N, \forall\, i \in I, t = 1, \ldots, 5 \qquad (8)$$

$X_{hkit} \in \{0,1\}$ $\forall\ (h, k) \in N, \forall\ i \in I, t = 1, \dots, 5$ (9)

Table 1

Notations used in the study

Indices	Description
h	Index of municipal nodes (*cabildo*) where products originate: h∈H
i	Index of transport modes: i∈I; 1= truck, 2= rail, 3= waterway, 4= fishing boat
j	Index of freight type based on the region and projected economic activity: j∈J
k	Index of critical nodes (Bluefields) where products terminate: k∈K
l	Index of roads being linked to enable transport from node to node: l∈L
t	Index for the year the mode was constructed: t∈T
Parameters	
C_{hkij}	Cost to move type *j* freight transported using mode *annual* from *h* to *k*
D_{hki}	Distance from *h* to *k* using mode *i*
IC_i	Infrastructure cost per kilometer constructed for mode *annual* in dollars
KM_{tIDB}	Cost, in dollars, of road constructed by the International Development Bank
KM_{hkil}	Length of road constructed, in kilometers, from *h* to *k* using mode *annual* that is linked
S_{jh}	Quantity of freight type *j* shipped by *cabildo h*
B_{IADB}	Construction rate for the Inter-American Development Bank project: 10 kilometers per year
Indices	Description
β	Discount rate for time (β= 1/1.05)
Decision Variables	
KM_{hkit}	Kilometers of mode *i* infrastructure built in year *t* from locations *h* to *k*
X_{hkit}	Equals 1 if *h* and *k* are linked by mode *annual* by year *t*
Y_{hkijt}	Weight of type *j* freight transported using mode *annual* from *h* to *k* in year *t*

Objective function (1) minimizes the total cost of building a multimodal transportation network that will enable the growth and development of a regional supply chain for local economic drivers. The model will support multiple products using a multimodal transportation network as well as logistics capacity for new supply opportunities. The first term represents the five main industries which will benefit from the new network as well as the transportation-mode types and infrastructure-construction costs. The second term represents the length of the infrastructure type, *annual*, as well as the year built using the Nicaraguan Central Bank's discount rate. The third term represents the cost and amount of material *j* transported throughout the network over a 50-year period from the points of origin, *h*, to the destination or critical node, *k.*

Constraint (2) ensures that all quantities of freight type *j* that are shipped from *h* are produced and/or harvested within a reasonable distance given the likely infrastructure investments and few resources; what is produced is shipped, meeting the region's supply potential. Constraint (3) limits the amount of freight shipped to the length of road constructed, meaning that products cannot be shipped without a viable road to facilitate the movement; transport will be based on annual construction of road estimates. Constraint (4) ensures that *cabildo*s are linked to Punta Aguila via Bluefields. Constraint (5) ensures that the transport modes have been constructed as well as linked prior to freight being transported from points *h* to *k*. Constraint (6) confirms that the length of constructed road or infrastructure is greater than or equal to the distance of the route necessary to move product *j* from points *h* to *k*. Constraint (7) ensures that road construction cannot occur faster than 10 times the rate of the Inter-American Development Bank project of 10 kilometers per year on any given arc. Constraint (8) determines what is feasible in terms of construction, e.g., the construction project could occur in a 5-, 10-, or 20-year period. Constraint (9) invokes integrality requirements.

The Model's Main Assumptions:

1. The transportation requirement is driven by economic development; although it would add more resources and a method to expedite construction, the Nicaragua canal does not have to materialize for this investment to occur.
2. Either the Nicaraguan government or investors provide adequate resources to complete the 5-year transportation-network construction effort. It is likely that international non-governmental organizations will underwrite this project given the paucity of resources available to the federal government.
3. Land-use changes are limited to 50% within *municipios*; for example, no more than 50% of the land can be converted from forest to cattle-grazing space. Examples in Latin America are, unfortunately, above 50% when one considers Brazil and Haiti (Laurance et al., 2001).
4. Each *municipio* that ties into the main transportation node (Bluefields) will start from the center city, or what is known as a *cabildo*. Each farm in the *municipio*, within 25 kilometers of the *calibdo* will be serviced by the transportation mode, e.g., road or waterway.
5. Bluefields is the hub's node and spoke transportation design because it is located just north of Punta Aguila which is uninhabited but will serve as the canal's deep-water port. In addition, Bluefields has and will build out the requisite infrastructure needed to warehouse, manufacture, and process products created from eastern-Nicaraguan communities.
6. Once transportation infrastructure is improved, lower transportation costs will increase the supply of Nicaraguan commodities and allow more goods to be some on international

markets. Growth in demand will be due to quality, price point, and the ability to get products to market.

7. Given the necessary transportation infrastructure, logistics capacity, and a functional supply chain, producers can meet domestic and international supply requirements for Nicaraguan products.
8. Nicaraguan suppliers and processors will use network infrastructure to move goods and services throughout the region.
9. Roads and/or other modes of transportation must be connected in order for the network to function as intended.
10. Network maintenance expenses are included with vehicle operation expenses although the funding for these components are expected to be separate.

Parameter 1.1. Road systems as well as potential infrastructure modes that will be built over five years; transportation requirements to meet the long-term demand and regional-modernization needs to enhance the livestock, crop, forestry, and manufacturing sectors

$$\sum_{t=0}^{5}\sum_{i=1}^{4}$$

For eastern Nicaragua to realize its full economic potential, it must invest in a variety of transportation modes to ensure that goods and services can be transported timely and inexpensively; and can meet the demand of growing domestic, regional, and global markets. Several hundred years ago, tribes across the area leveraged an unsophisticated network of *adoquines* to meet that time's requirements (Zafra, 2018). Unfortunately, the Spanish and, subsequently, Nicaraguan governments did not invest in transportation modernization, leaving the region among the most-impoverished areas in Latin America. With the potential of a major economic-development project on the horizon along with economic transformation, Nicaragua is positioned to invest in its future through transportation upgrades. Presently, there are several highways which connect the RAAN and RAAS communities to either Managua or regional capitals; however, if these regions are to develop, 9- or 10-ton roads or some type of rail system will be required to modernize the autonomous regions' economies.

It is important to note that the costs to import goods and to orchestrate construction will not deviate greatly because the same challenges exist for all stretches of road. In addition, roads will not be recommended for all transportation routes because current and projected economic activity may lead to a recommendation for canal transportation using the current waterway network and/or railways. This assessment includes current transportation options and suggestions for the region's complete transportation overhaul.

Parameter 1.1.1. Bocana de Paiwas

It is not recommended that additional investments be made for transportation infrastructure due to an adequate highway which is already in place. The proposed canal would provide additional export opportunities, but with economic growth comes disposable income, so the capital region will likely purchase more beef from this municipality and its environs if there is a demand. Growth may be slower on this road because it is not a 10-ton road, but additional economic activity will occur due to changes in the region.

Given the expansion of cattle ranching over the last several decades, additional economic activity in the region, coupled with increased disposable income, will assist Bocana de Paiwas in its desire to increase beef production. New investments for regional transportation infrastructure will create a logistics capacity that did not exist before, leading to an opportunity for increased timber harvesting due to access to international supply chains.

Parameter 1.1.2. Corn Islands

The Corn Islands are separated by the Caribbean Sea. Investments regarding improved transportation to connect with the mainland are unnecessary given the area's dependence on tourism and undeveloped beaches. With additional mainland infrastructure, tourism to the islands may increase along with job opportunities for a growing service industry.

Parameter 1.1.3. Desembocadura de la Cruz de Rio Grande

In the model, there is an also an opportunity for local fishing companies to increase their capacity and to use a larger fishing-boat fleet in order to move their products to Bluefields and, subsequently, to market; however, there is no need for major road expansion. As such, either a small road project may ensue, or investment in additional fishing-boat capacity should be anticipated if opportunities come to fruition in the region.

Parameter 1.1.4. El Ayote

Given the city's connection to Highway 7, it is not recommended that additional transportation-infrastructure investments be made due to the adequate highway that is already in place. Future analysis should occur as the regional economy changes and requirements evolve.

Parameter 1.1.5. El Rama

El Rama has a basic logistics infrastructure in place to accommodate the current trade and transportation requirements. Expansion in this community is almost certain. In addition, El Rama is connected to the capital by road and to Bluefields. The primary issue with the road network that serves Bluefields pertains to inadequate weight requirements. Due to plans to connect Bluefields and Nueva Guinea, future improvement for the current road is unlikely. Growth in El Rama will persist due to regional trends and access to the capital, but new infrastructure is unlikely in the near future due to El Rama's current regional-hub status and the likelihood to grow as new economic opportunities become available in the region. It is important to note that the road being constructed from Bluefields to Nueva Guinea will propel Nueva Guinea into a more-important economic hub. With or without the canal project, El Rama may experience a reduction in its status as the inland RAAS hub.

Parameter 1.1.6. El Toruguero

El Toruguero is an area that is surrounded by dense forests. As a result, it is anticipated that economic activities, primarily in ranching, will lead to the expansion of existing operations and a requirement to have a stable road in order to ensure timely exports. In addition, this area has been explored for timber production in the past. The total road length will be 42.6 kilometers and will connect to the road that will be built connecting Camp II to Kukrahill. Figure 5 illustrates this connection versus a road that will go from Rama or directly to Bluefields.

Given that logs and cattle, the likely regional exports, can be transported via boat and a river with suitable capacity, exploring river transportation as an alternative mode is essential to minimize the network's costs. Throughout the world, river- and ocean-bound livestock carriers operate. Voyages that range from days to a month are not uncommon.

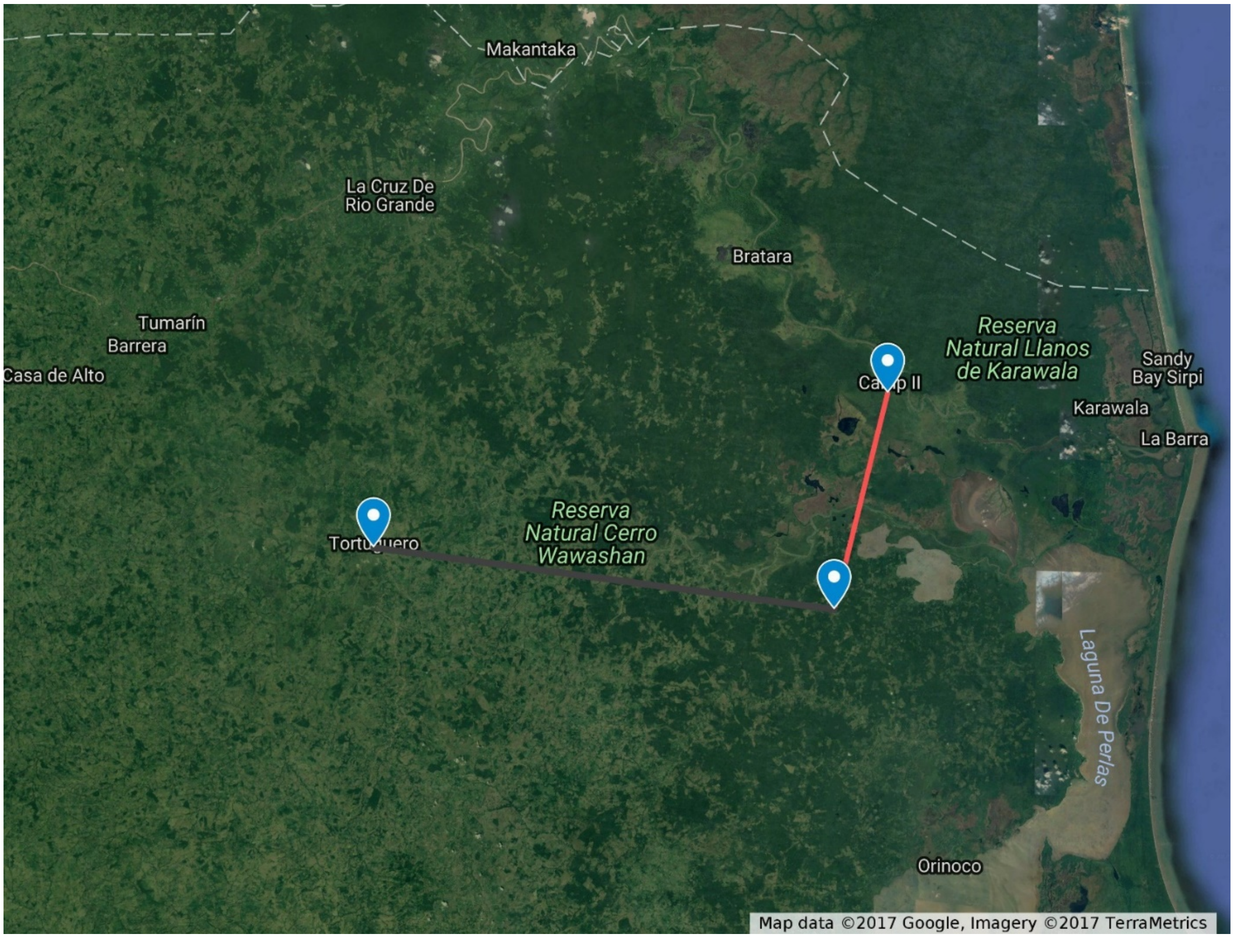

Figure 5. Proposed route that connects Tortuguero to a road that will be established (in red) from Camp II to Kukrahill.

Expanding the river system may also accommodate the anticipated growth of the region's cattle industry. If a processing facility were established locally and enabled exports to meet international standards, it is quite possible that the river system could provide a viable transportation option. Figures 6 and 7 illustrate the inland river system.

Figure 6. Proposed expansion of the Rio Kukarawala River to the Rio Kurinwas River, enabling cargo traffic to travel to Laguna de Perlas and, subsequently, the port at the southern end. Waterway expansion is highlighted in red.

Figure 7. Closer view of the proposed river expansion of the Rio Kukarawala to the Rio Kurinwas River for additional river-transport capacity.

It is important to highlight the value of inland water transportation in Nicaragua. Since the inception of native civilizations in Central America, inland-waterway transportation has been critical to the regional way of life. Inland waterways have been used to transport goods in order to facilitate trade, to enable the movement of materiel for conflict, and to remain a primary component of the local logistics models. As a result of river dependency and modern inland-waterway transportation, it is important to consider this mode as an option for the long-term viability of local economic-development and growth models. Given the lack of road infrastructure, many communities use inland waterways as their primary source of connection to the outside world. Given El Tortugeuro's geographic isolation, its lack of road infrastructure, and its proximity to major waterways, it is prudent to price a model which is consistent with the existing trade patterns that would enable the municipality to enjoy similar growth as the communities serviced by roads.

It is difficult to price waterway-development models for inland transport. In the region, we have examples that are focused on the Panama Canal, so there are few direct correlations to cost models. In Europe and the United States, some research concerning waterway-infrastructure development costs as well as long-term operations and maintenance expenses has been documented; however, the regulatory environments, labor standards, and costs of doing business are very different in Nicaragua. To estimate the costs for the 15 kilometers of waterway expansion from the Rio Kukarawala to the Rio Kurinwas Rivers (The depth and width of the Rio Kurinwas River will facilitate a majority of the cargo traffic which originates in El Tortugero during the rainy season and, to some degree, the dry season.), assumptions will be made concerning the requirements, labor costs, and regulatory standards as they pertain to what was accomplished in the United States and Europe. It is important to note that population densities in

Europe are much higher than in eastern Nicaragua. Therefore, the costs may be different; however, traffic may be higher in Nicaragua due to the quantity of anticipated product movement.

Before exploring the expenses associated with developing an effective and modern inland waterway-transport system (15 kilometers) that will accommodate much larger beef-export capacity, it is important to understand the current challenges associated with inland-waterway transportation. According to the National Academy of Sciences, Engineering, and Medicine (2015), over 80% of lost transportation hours are due to delays. A majority of the delays occur as a result of congestion during seasonal shipping peaks and frequently occur at high-demand locks and/or docks used to transport agricultural exports. When one considers how quickly harvest occurs, followed by loading, transporting, and subsequent sale, it is no surprise that the peak demand for agricultural products leads to lost transport time. Given how beef is locally processed and the RAAS region's lack of processing and safe-transport capacity, it is critical that these delays are mitigated in model development. A proper scheduling protocol is required to ensure that these issues are addressed prior to shipment.

Parameter 1.1.7 Kukra Hill

Kukra Hill will benefit greatly from improved infrastructure in the region. Currently, Highway 7 connects this community to El Rama, providing the ability for this type of growth and expansion to occur should regional infrastructure become a reality.

Parameter 1.1.8. La Cruz de Rio Grande

La Cruz de Rio Grande requires infrastructure to realize its growth potential. With respect to implementing more-effective transportation options in order to facilitate economic development and improved trade, there are two viable options. Due to its centralized location in the northern RAAS region, a road can be constructed to either connect cities along the Caribbean coast or to the communities in the western part of autonomous regions where road networks connect with the capital. Another option would be to improve the river's navigability by widening it. Just to the west of the city, there are areas where navigability is viable; further to the west, the river is not navigable. The river can be widened in areas to the east until it reaches the road network that will, one day, connect the coastal communities with Bluefields.

To avoid as much of the Cerro Wawahan Nature Preserve as possible, approximately 10-15 kilometers of 10-ton road will be added. With new road, the network avoids areas that would be too close to Pearl Lagoon in order to mitigate the risk of flooding.

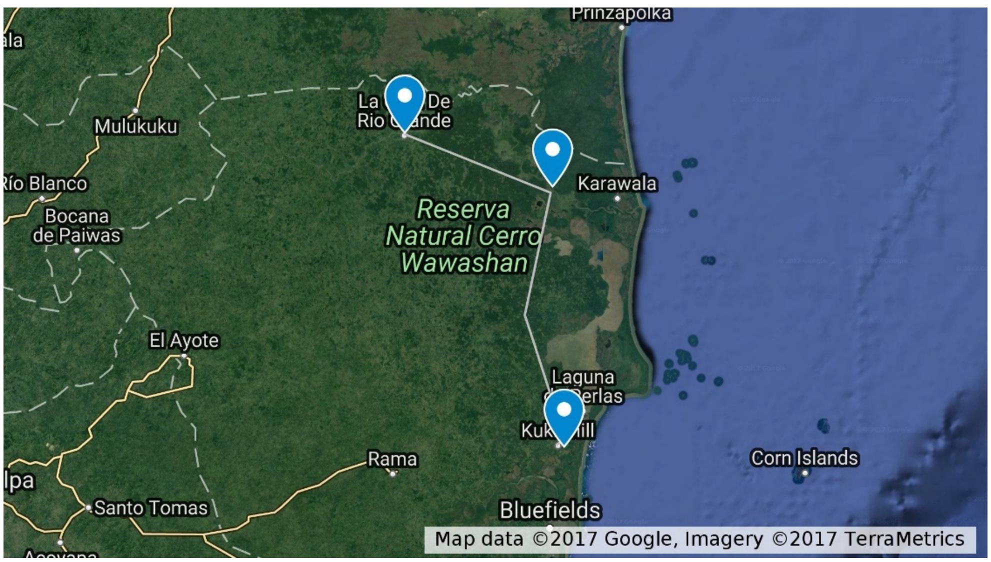

Figure 8. Proposed route that connects Cruz de Rio Grande to Kukrahill via Camp II.

Although this community is connected to the second-largest river in Nicaragua, river transportation will be limited to the east due to the construction of the Tumarin Dam and hydroelectric complex. Given the city's dependence on the river, the road is critical to the city and the municipality in the future because the river enables economic growth and development.

Parameter 1.1.9. Muelle de los Bueye

Muelle de los Bueye is connected to Managua via Highway 7; as such, additional investments for transportation infrastructure are not recommended due to an adequate highway that is already in place.

Parameter 1.1.10. Nueva Guinea

Nueva Guinea will realize its potential as the remainder of the network comes online. It can be assumed that, with additional export capacity and the international price of beef, the domestic-demand supply could suffer due to the focus on international export opportunities; it is very possible that Nueva Guinea may meet the domestic-supply-and-demand imbalance should it become a secondary effect of new transportation, logistics, and export opportunities for both the RAAN and RAAS regions. As such, a good portion of the projected environmental damage may come from this area. Currently, a project to connect Nueva Guinea and Bluefields is being planned. The Inter-American Development Bank (IDB) has approved a loan to connect the Atlantic coast with the rest of the country. This project was approved in late 2014. As a result, 73 kilometers of road infrastructure will be constructed from Nueva Guinea to Bluefields. The request for proposal in 2015 developed by the Government of Nicaragua and the IBD places the estimate at $62,761,000; this amount includes bridge requirements and special construction criteria in swamp areas.

Figure 9. Map demonstrating the proposed route from Bluefields to Nueva Guinea (light green) and the existing inadequate route from Bluefields to El Rama (IDB, 2014).

For additional perspective about what road conditions existed, the Inter-American Development Bank, working in conjunction with Nicaraguan transportation planners, took photos of the existing infrastructure; the date, time and locations along the route are unknown. In October 2018, the Inter-American Development Bank was contacted to discuss the pictures but the request went unanswered. As such, there are no specific figure numbers that correspond to the pictures as the date and origin are unknown. Like many roads in the coastal region, dirt paths dominated the vehicular-transportation options along with the basic maritime-shipment infrastructure.

For technical perspective, the IBD team documented the most-important and challenging areas associated with new road construction, e.g., areas which have to traverse swaps and forests. The photos below document some of the more-demanding areas associated with road construction. Also note that other road construction associated with this dissertation will have to negotiate similar obstacles; therefore, $845,835 per kilometer was priced for the project’s other legs.

Parameter 1.1.11. Pearl Lagoon

Kukrahill is only about 9 kilometers from Pearl Lagoon; as a result, a small road can be constructed to meet the Nicaraguan highway system. Pearl Lagoon can then realize its potential beyond tourism.

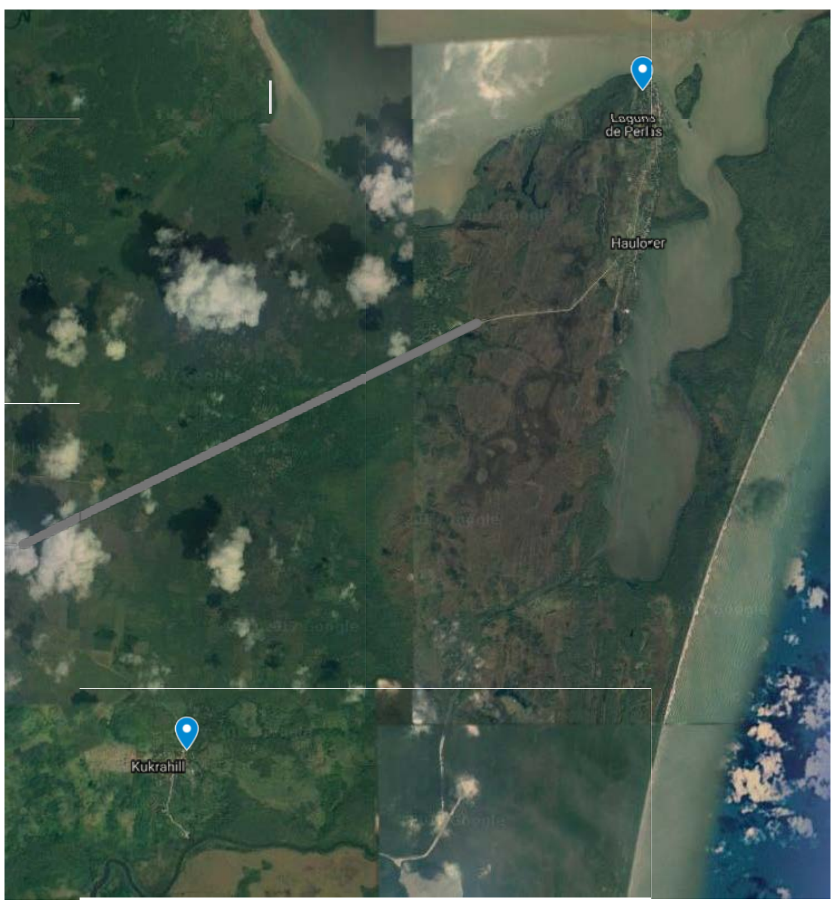

Figure 10. Road from Pearl Lagoon connecting to the Nicaraguan interstate system north of Kukrahill.

Another option that is examined is in the methodology's cost to transport goods. In essence, the fishing industry can still expand as a result of new demand and processing opportunities in Bluefields. Costs to transport the catch from the coast of Laguna de Perlas to Bluefields is examined given the projected industry growth. This additional transportation mode is analyzed to determine if it contributes to lower expenses for the cost-minimization model. The distance via the Caribbean Sea is 38 kilometers.

Parameter 1.1.12. Bluefields to Punta Aguila

For the RAAS region, it is evident that localities need to be connected to communities with road networks to Managua or rural areas where it would make economic sense to build an interior highway network to Bluefields. Should the canal be constructed, however, a deep-water port will be required at Punta Aguila. As a result, traveling from Bluefields to the new port will be required as the last leg of the logistics network in a global supply chain. It is important to determine the most-effective transportation mode; as evidenced by the costs highlighted for the planned road from Bluefields to El Rama, it would be prudent to examine an alternative mode, such as a railway, to determine the expenses associated with construction, operations and maintenance, and energy usage during the prescribed cost-benefit period of 50 years.

Road construction will be approximately 62.1 kilometers to ensure that minimal damage is done to nature preserves. In addition, it is necessary to travel west in order to avoid swamps and water systems, creating a longer road requirement.

Figure 11. Road that will be constructed from Bluefields to Punta Aguila; it will be constructed west and then southeast to avoid as much environmental degradation and swamp land as possible. Should the canal not come to fruition, the deep-water port location may change be based on the assumption that the canal will necessitate a large, deep-water port.

If the canal is built along with the corresponding road infrastructure, it is likely that Bluefields will grow into a larger economic hub for the RAAS and RAAN regions. It is anticipated that a new deep-water port, coupled with major economic-growth activity and the ability to export local products into global supply chains more efficiently, may lead to the creation of a free-trade zone. Given that the deep-water port will be located in a sparsely populated area, a majority of the free-trade activity, which will be addressed later in this chapter, will occur at Bluefields. Therefore, it is important to consider rail as an alternative to road construction from Bluefields to Punta Aguila.

RAAN communities are pretty-well connected to major cities in Nicaragua. As a result, an analysis of requirements was conducted, yielding the following results.

Parameter 1.1.13. Bonanza

Given access to Highway 30, as well as current and projected economic activity, no additional transportation investments are recommended. As the network matures, investment plans may change.

Parameter 1.1.14. Mulukuku

At this time, the area is adequately served by the Nicaraguan highway system. Therefore, no additional transportation investments are recommended. As the network matures, investment plans may change.

Parameter 1.1.15. Prinzapolka

Given its economic potential, especially in the realm of fishing, Prinzapolka requires additional infrastructure to facilitate growth. It is proposed that a road be constructed from this area to Bluefields. The same road would connect several communities in the northern RAAS region and also Puerto Cabezas, thereby enabling fishing-industry expansion. This connection totals approximately 101 kilometers.

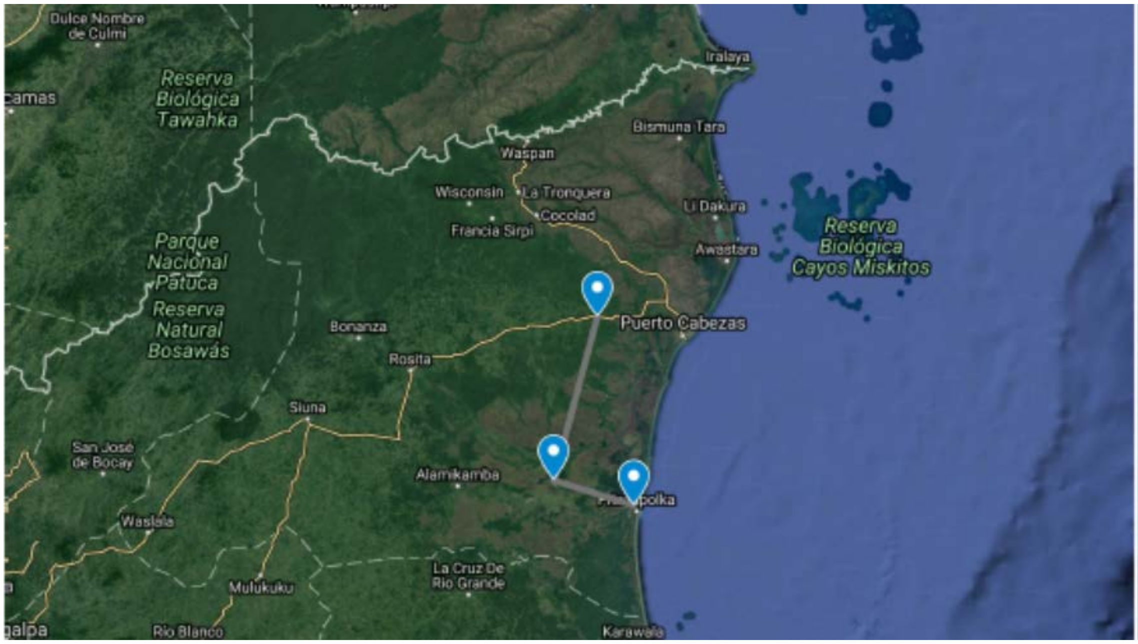

Figure 12. Road that will be constructed from Prinzapolka to Puerto Cabeza, connecting many communities which are dependent on coastal economic activities; it will be constructed west and then southeast to avoid as much environmental degradation as possible along with the bodies of water where construction is impractical.

Parameter 1.1.16. Puerto Cabezas

At this time, the capital is served by major roads and is connected to larger economic hubs in Nicaragua. Therefore, no additional infrastructure is recommended.

Parameter 1.1.17. Rosita

With access to Highway 28B and the projected activity, no additional transportation investments are recommended. As the network matures, transportation plans may change.

Parameter 1.1.18. Siuna

Siuna is easily connected to both Puerto Cabezas and Managua. No additional transportation investments are recommended. As the network matures, transportation planning may change.

Parameter 1.1.19. Waslala

No additional transportation investments are recommended at this time given the proximity to Matagalpa and the road-network access to other major metropolitan areas. As the network matures, requirements may change.

Parameter 1.1.20. Waspam

Given access to Highway 73, no transportation investments are recommended as part of this network's interconnectivity. As the network matures, transportation requirements may change.

Parameter 1.2. Infrastructure Costs

$$IC_i$$

Table 2

Infrastructure costs

Parameter	Estimate	Source
Road-construction cost (includes bridges): KM_{itIDB}	$846,000/km	Inter-American Development Bank (IBD)
Discount rate	5%	Central Bank of Nicaragua
Railway-construction cost	$1,134,375/km	Compass International
Waterway-expansion cost	$4,000,000/km	Association Internationale de Navigation
Truck-transport cost	$.1028/Ton-km	United States Department of Transportation (USDOT)
Rail-transport cost	$.0252/Ton-km	USDOT
Waterway-transport cost	$.0114/Ton-km	USDOT
Fishing-boat transport cost	$12.28/Ton-km	Assumption (Bose and Sharma, 2010)
Annual cost to maintain roads	$8,741/km	United States Forest Service
Annual cost to maintain railways	$58,046/km	Jovanovic
Annual cost to maintain waterways	$331,270/km	Association Internationale de Navigation

Each assumption is explained, in detail, in this section. Any major infrastructure project it is likely to encounter changing conditions that alter the transportation network's planned construction. Therefore, there are a number of alternatives which must be considered in order to reflect a more-realistic approach. Using the model, there are a number of scenarios which will be examined given that alternative courses of action exist for planners. In addition, Nicaragua is a highly impoverished nation, and there is a high probability that limited resources and dependence on foreign investment, e.g., from China, will influence the network's development. These alternative outcomes are tested to determine how the model responds to likely adjustments based on fiscal and political realities:

1. No canal construction (Construction of the road network occurs over 5 years.)
2. Land-use conversion limits based on lumber and cattle growth, capped at 50%: in some regions, there is potential to increase in areas with inadequate enforcement
3. Discount rate changes due to market forces (now 5%): will test 15%
4. Amount of road construction per year to meet the 5-year construction requirement
5. Cost of moving products from points of origin using different infrastructure types increasing or decreasing due to higher or lower transportation rates

With this model, each municipality within the northern and southern autonomous regions was evaluated based on soil type, climate, existing infrastructure, and current industry to determine which outputs would be anticipated in the community. Outputs are based on data from the Nicaraguan government and international non-governmental organizations (NGOs) as well as current economic activity. For example, El Rama is likely to be more suitable as a crop-and-livestock transition mode versus a light-manufacturing location. The economic activity determines the transportation-infrastructure requirements and what contributions to the logistics and supply chain networks will occur; e.g., higher cattle production equals more beef exports.

The price of the commodities and products sold is based on rates during the fall of 2017. It is known that prices fluctuate and must, therefore, retain some baseline for consistency. The output for livestock and crops is based on anticipated land-use changes as a result of the new transportation infrastructure and export opportunities.

Transportation costs are based on prices for construction material in the fall of 2017; estimates include both highway-development expenses and the costs for rail. Dredging waterways and determining how to create water systems that can be used to transport goods throughout the year are based on labor rates and equipment charges.

Parameter 1.2.1. Caribbean Sea transport

The cost of transporting seafood is based on Bose and Sarma's (2010) estimates for Indian vessels. The per-voyage cost averaged 90,000 Indian Rupees, or $1,326. A voyage averaging 12 hours at 9 kilometers per hour with the capacity for about a ton of catch is the major component of the assumption. Because fuel expenses are less expensive but wages are higher in Nicaragua, the baseline estimate is likely within a reasonable margin of error.

Parameter 1.2.2. Road-construction cost

To determine the costs associated with road infrastructure, the following assumption is used to quantify the expenses associated with bituminous asphalt roads that have a 10-ton base: $845,835 per kilometer of construction. This number is derived from the total expense associated with the IBD estimate for developing road infrastructure from Rama to Bluefields: $62,761,000 for 74.2 kilometers of road. The estimate also includes the funding necessary to repair and build bridges along the route (Inter-American Development Bank, 2014).

Parameter 1.2.3. Inland-waterway cost

If a well-engineered waterway were constructed to canalize an existing river and make it suitable for large-scale transportation in Europe, the cost is estimated to be about $6,000,000 per kilometer (Association Internationale de Navigation, 2005). The association's estimate ranges from €5,000,000-€20,000,000; however, this amount included new canals, hilly terrain in response to lock requirements, and a number of inputs that are unlikely in Nicaragua. Because the terrain is much flatter and the canals are already used for navigation, it is assumed that expenses would be toward the lower end of the estimate spectrum conducted by the association's subject matter experts. It is also important to note that traffic is estimated to be much lower in Nicaragua, given the sparsely populated region; fewer requirements are likely due to regulatory differences. Lastly, labor is much-less expensive in Nicaragua than in Europe; the materials required to orchestrate this project are estimated to be constant. For the purposes of this dissertation, it is assumed that the cost per kilometer will be $4,000,000, given the input-cost differences and the estimates required for work given how advanced the inland water and transport system is in the RAAS region.

Although a majority of the European-waterway work was done prior to environmental-impact assessments, it is important to note that environmental-damage mitigation efforts could increase the cost. Some of these expenses may be offset by less-expensive labor and fewer environmental requirements.

Other elements related to forecasting the expenses associated with constructing and maintaining inland waterways for transportation were difficult to ascertain. In a recent report commissioned by the European Commission (ECORYS) indicated that the literature does not contain many estimates for the marginal-infrastructure costs of inland waterways, likely due to the fact that only a handful of European nations have extensive inland-waterway networks which are utilized for trade. As such, the approach to determine the marginal costs for inland-waterway operations and maintenance focused on infrastructure, safety, environmental, and congestion costs; how these expenses were related to inland shipping, additional vessels, and the variety of vessel types were also considered. The ECORYS study, however, was able to capture the costs for embankment preparation and maintenance, river dredging, lock and bridge maintenance, repairs, and operations.

Looking at the cost figures available for 2001-2003, ECORYS developed an econometric approach, albeit not an elaborate one given the short analysis period, to determine inland-waterway maintenance costs for each kilometer of waterway. These operational and maintenance expenses included a number of variables. First among the variables was locks. Interestingly, a weak correlation existed between lock-maintenance expenses and the number of vessels that utilized the facility. For the purposes of connecting El Tortugero to broader markets, the lock requirements were minimal given the minimal surface-elevation change throughout the network. Maintenance expenses for embankment, however, did have a direct correlation between the vessel traffic and the requirements given the waves created by traveling ships (ECORYS, 2005).

Parameter 1.2.4. Rail cost

Compass International, Incorporated (2017), an engineering firm which specializes in railway design and development, estimates that a single track's ideal cost is $1,134,375 per kilometer. This cost includes railway-bed prep; command and control; and all of the construction equipment and supplies necessary, e.g., railway ties, to construct a kilometer of railway that can support freight and cargo movements to this scale. Given the lack of current economic activity and the anticipated demand for regional products and exports, it is assumed that a single track will be adequate to accommodate economic activity. Compass International, Incorporated provided a spectrum of expenses, and given the terrain work, e.g., preparation of a railway bed in a swampy area, that needs to occur in the area, high side estimates are justified. For this level of economic activity, two freight trains are appropriate; one train can run product back and forth from the Bluefields node to the export facility at the deep-water port while the other train is loaded/offloaded and vice versa.

Compass International, Incorporated’s (2017) estimates assume prime conditions and reflect what costs should be; however, many recent examples in the developing world tell a different story. In Nigeria, Chinese companies completed a new track in 2008; the total project cost $5.81 billion and encompassed 1,315 kilometers (Brautigam, 2010). Local officials acknowledged that the Nigerian price tag was twice the necessary cost for the project; ideally, each kilometer of single track should have cost $1.5 million, but it cost slightly over $3 million. According to Brautigam, other projects in the developing world included a new Afghan railway which cost $2.26 million per kilometer to construct and $4.7 million per kilometer in Libya. Given that there are ideal costs and local realities, such as inefficiencies and corruption, it is assumed that the cost for rail in Nicaragua will likely be $2 million per kilometer.

Parameter 1.2.5. Alternative scenarios: transportation expenses using different configurations and estimates

Parameter 1.2.5.1. Trucks

For the model’s purposes, the cost per ton-kilometer for transporting goods was assumed to be equivalent to expenses in the United States. Although the transportation cost is different in Nicaragua, this assumption was made because of a new road network. In Nicaragua, the existing transportation-and-logistics costs and obstacles are a direct result of poor road quality as well as externalities. According to the World Bank (2012a), there are several reasons why transportation is more expensive in Central America than in the United States, including, but not limited to, higher fuel prices, security costs, high rates of transfer involving empty containers, excessive travel times, and scarce investment access. When examining the situation in Nicaragua, the cost becomes even more expensive than neighboring countries.

Parameter 1.2.5.1.1. High fuel prices

Refining capacity in Nicaragua is inadequate, resulting in frequent price fluctuations as well as shortages. The instability associated with the nation's refining capacity can result in higher fuel prices, increasing the cost to ship goods throughout the country. In addition, trucks tend to be older and, therefore, not fuel efficient. Also, over the last several decades Nicaragua has aligned itself with Venezuela given ideological similarities; the instability in Venezuela has likely led to additional fuel supply challenges. Coupling the operation and maintenance reality with poor transportation infrastructure and fuel inefficiencies greatly increases costs. A prime example for the effect of road quality and obstacles which affect transportation costs pertains to family ranches. For smaller producers, the distance to the slaughterhouse is greater where roads are unpaved. The road conditions and distance increase transportation expenses by 350% (World Bank, 2012a) when compared to a larger producer with access to paved roads; in addition, the time it takes to get to slaughter from the point of origin increases 250%. A new road network will mitigate many of these challenges in the RAAS and RAAN regions, given the proximity to better infrastructure, thereby reducing the overall logistic burden for producers in the areas affected by the transportation project.

Parameter 1.2.5.1.2. Security costs

Compared to other Central-American nations, Nicaragua has one of the lowest crime rates. Therefore, security costs, e.g., armed escorts, are less frequently used when transporting goods. Compared to the United States, rates are still much higher, over $400 per year per vehicle (World Bank, 2012a). These costs are built into the overall pricing per Ton-kilometer.

Parameter 1.2.5.1.3. Transferring empty containers

Many Nicaraguan truckers return to their point of origin without backhaul opportunities. The traveling empty situation occurs for several reasons: long wait times at border crossings discourage returning with a full load; most shipping occurs through direct contracts, causing a lack of coordination for the supply and demand; and government inefficiencies exist.

Parameter 1.2.5.1.4. Excessive travel times

Given the security situation in Central America, border-crossing times have increased due to more inspection scrutiny. Also, government inefficiencies and corruption contribute to already long wait times. Many regional truckers encounter similar corruption as well as inefficiencies at weigh stations. These long waits decrease fuel efficiency and create higher wage requirements to ship goods.

Parameter 1.2.5.1.5. Scarce investment

Unlike the United States, access to capital is difficult to obtain. As a result, many trucks are antiquated and inefficient. Also, in the developed world, many transportation companies enjoy credits to renew or maintain their respective fleets due to the desire to reduce emissions and to improve air quality. In Nicaragua, access to capital is difficult to obtain, and tax incentives for upgrading fleets are non-existent.

Logistics Expenses from the Farm Gate to the Slaughterhouse Nicaraguan Beef Export Chain		
Large Producer		**Small Producer**
35 paved km	Distance to Slaughterhouse	144 km, most unpaved
$4/animal	Transport Expenses	$14/animal
Low	Probability of Injury	High
>2.5%	Loss of Carcass Weight in Transit	<5%
About 30 hours	Total Time from Departure to Slaughter	Up to 3.5 days
US$2.84	Farmer's Received Price per kg of Meat on the Canal	US$2.76
US$0.15	**Total Logistics Burden per kg**	**US$0.32**

Figure 13. Logistics expenses from farm gate to slaughterhouse (World Bank, 2012a).

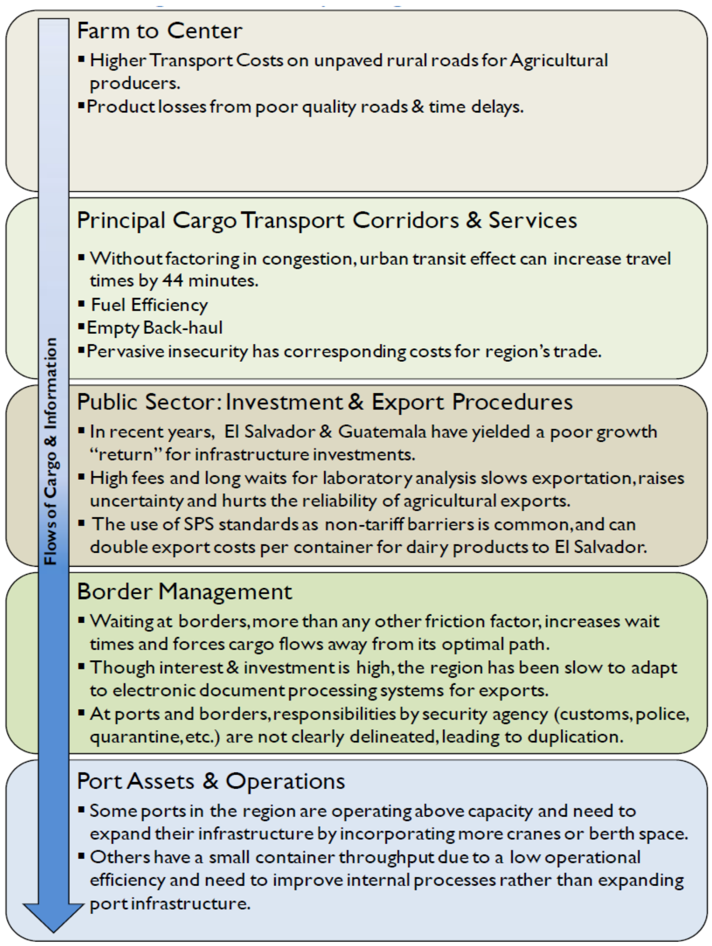

Figure 14. Inefficiencies associated with Central American logistics networks (World Bank, 2012a).

Given the constraints and obstacles created by inefficient logistics models as well as poor transportation infrastructure, estimates are that it costs $0.017 per ton-kilometer to transport goods across Nicaragua (Secreteria de Integracion Economica Centroamericana, 2018).

Compared to the United States, the Nicaraguan cost is roughly two-thirds higher, even with the more-expensive trucking units and labor costs in developed nations.

In this study, rates associated with the United States were used to reflect the likelihood that modern transportation infrastructure, especially if a canal were constructed, would likely attract modern vehicles. This assumption is based on having newer vehicles purchased and transported to Nicaragua in order to assist with building the canal. After construction, these vehicles would be used locally and given new economic opportunities, operations and maintenance as well as newly discovered efficiencies associated with modern vehicles, would be available for the first few years. Given the region's economic growth, a cycle would evolve, thereby offering a mixture of newer and older vehicles which are available in the region.

Parameter 1.2.5.2. Trains

Like truck transport, the United States, through efficiency as well as effectively planned/executed maintenance and the use of state-of-the-art systems, tends to offer lower railway transportation costs than the rest of the world. According to the United States Department of Transportation (2014), aggregate average costs to use rail equal $0.0252/Ton-km; Average cost of rail car is a collection of all configurations and car types. In the first model which was tested, the United States cost was used for two reasons: first, the RAAS railway infrastructure would be new; as a result, one would anticipate the purchase of new and efficient locomotives. Second, given the new manufacturing industry within the proposed free-trade zone/manufacturing complex in addition to the contemporary deep-water port infrastructure at Punta Aguila, transloading capacity would also be modern, requiring new locomotive infrastructure. Holistically, given the short distance and new infrastructure, costs should not deviate drastically from the United States.

However, the reality is that, in time, Nicaragua would join the low- and medium-income nations with respect to its railway efficiencies and costs to operate the system. This difference is due to a number of reasons: traffic density in the United States is very different than Latin America as well as Europe; as a result, Nicaragua will likely have prices which are commensurate with other nations with similar geography and population densities. From here, it is likely that investments for maintenance will resemble those of developing nations. Additional regulations and fewer well-positioned companies in Central America may lead to lapses in maintenance, including track and locomotive infrastructure. Unfortunately, these expenses will transition into inefficiencies for fuel usage and other maintenance challenges, increasing fuel prices. A solid cross-section of 19 railways operating in Latin America provide a glimpse into what Nicaragua may experience in the coming years. With respect to an average for the 19 railways, Ferrovia Tereza Cristina was removed as an outlier, leaving 18 companies operating in Brazil, Peru, Argentina, Chile, Bolivia, and Mexico. The average cost to move goods per Ton-km is $0.0462, almost twice the cost in the United States (OECD, 2014).

Outside Latin America, rates, to include both crop and livestock movement, differed. One, the cost of moving goods across Europe was much higher; in eastern Europe, costs were lower than for the western part of the continent. Many nations average three or four times that of the United States and Canada, likely due to different labor arrangements, stricter emission standards, and higher population densities. Interestingly, in India, prices were comparable to the United States and Canada. To move products, after converting rupees to dollars, commodities such as wheat, livestock, sugar, and coal were comparable to the United States. Indian railway lines use diesel and electric locomotives but, for the most part, adhere to very few environmental standards. Since the colonial period, India has maintained an effective rail network. These expenses, coupled with low labor costs and transfer payments, enable inexpensive Ton-km rates.

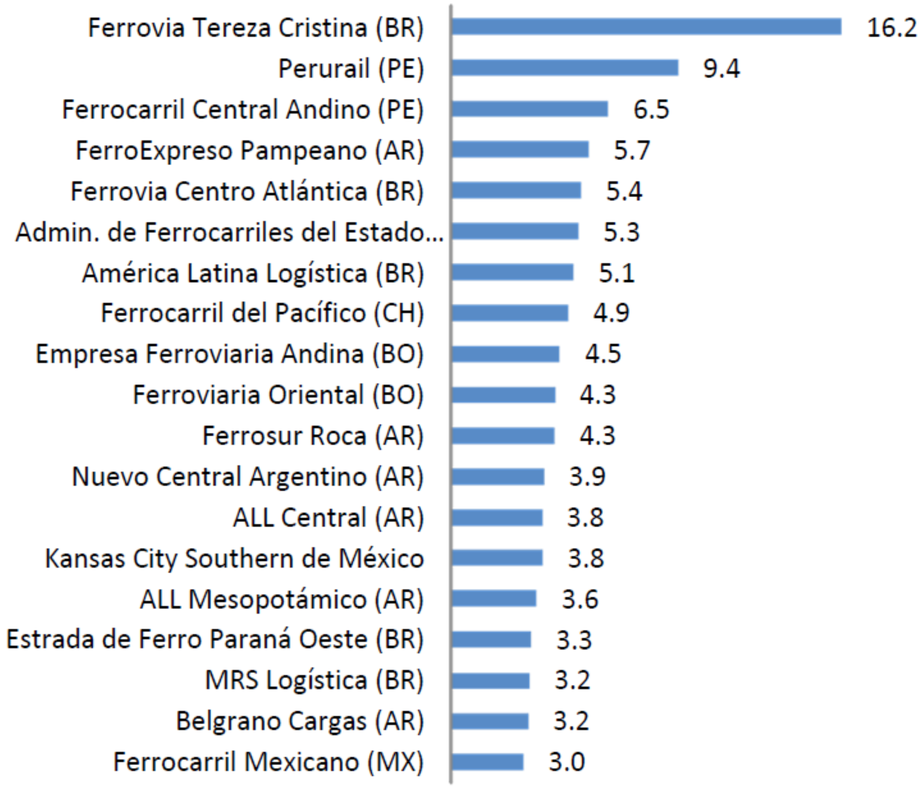

Figure 15. Average cost in 2013 per rail Ton-km (Organisation for Economic Co-Operation and Development [OECD], 2014).

Parameter 1.2.6. Economic benefit to society

Overall, this model determines the most cost-effective transportation modes and investments. This network is being constructed to improve the total returns to society as a result of transportation development in Nicaragua's autonomous regions. The intent is to minimize the costs for transportation development. The network will be developed in order to enhance societal benefits based on modernization which is directly and indirectly attributed to new transportation networks. This network will also enable development and economic growth from the new logistics capacity in order to transport goods and people throughout the nation; it will also facilitate Nicaraguan integration and expansion into global supply chains which originate from new and/or expanded opportunities, such as crop development, livestock growth, manufacturing development, and other economic opportunities.

Parameter 1.2.7. Factors selected to influence the model

This dissertation focuses on minimizing the transportation costs associated with developing a modern, multimodal network which is based on economic- and community-development requirements. To better appreciate the environment and why the model was constructed to reflect specific geographic requirements, it is important to know and understand both the assumed benefits and costs associated with this plan, especially as they pertain to the logistical capacity development for large economic sectors and further integration into the global supply chain. Without the road network, many of these opportunities are unlikely to come to fruition; it is important to reiterate that the main catalyst for this model is constructing the Nicaragua canal; however, transportation development without canal construction may yield similar economic-growth benefits for the region. Overall, this project encompasses transportation-network construction, logistical capacity development based on transportation opportunities, and the effect that the transportation-and-logistics capacity will have on the overall global supply chain integration in areas such as beef and fish harvesting, cash-crop exporting, and light manufacturing which occur in a free-trade zone.

The aforementioned factors collectively identify the amount of freight that will be moved throughout RAAN and RAAS communities as a result of the new transportation infrastructure, logistical-network development, and overall supply chain integration. A majority of the assumptions that lead to quantifying freight tonnage are based on existing economic activity in eastern Nicaragua and reflect the development potential based on similar transportation models in countries with free-trade zones and comparable climates.

Parameter 1.2.8. Short-term transportation requirements to meet canal-construction needs

If canal construction were funded and came to fruition, the benefits for the region are huge given the potential for growth, development, and modernization. The HKND Group (2014) outlined its construction and operational requirements to build the canal. In the eastern third of the project's region, modern transportation infrastructure is currently elusive because seasonal waterways and Mayan-era *adoquines* (cobblestone) networks provide some travel capacity. The project proposal, however, was quite clear with respect to the type of equipment, energy resources, construction material, and operational requirements which are necessary to move forward. According to HKND Group (2014), to meet basic construction needs, over 2,000 pieces of heavy equipment; 5 billion liters of diesel fuel; 400,000 tons of explosives; and a million tons of cement and steel will be mobilized. To orchestrate this level of equipment mobilization, modern roads are needed because the river system and the lack of associated infrastructure are not prepared to meet these standards.

In 2014, the Inter-American Development Bank developed a loan proposal to meet road connectivity and construction requirements that were within a few kilometers of the proposed canal route. The proposal focused on Atlantic-coast interconnectivity using a road originating from Bluefields and connecting with Nueva Guinea. In 2014, the total estimated cost for the project was approximately $63 million. The road's intent was to facilitate the connection of the RAAS region with the remainder of the nation, thereby integrating economic activity; the bank study focused on improving both the tourism and fishing industries.

Other study benefits include a projected 40% reduction for passenger travel time throughout the region as well as a 71% reduction in freight transport. Approximately 53,000 RAAS inhabitants will directly benefit from road construction according to the IDB (2014) estimates. In addition, the road could double as an enabler for the HKND Group's transportation-infrastructure requirements should the canal come to fruition. In a perfect situation, project would take 5 years to build. The announcement was made in 2014 with planning into 2015. At the end of 2016, five kilometers of road were constructed, and by September of 2018, ten kilometers of road were built with an estimated completion at the end of 2020 (IBD, 2018). Every month, the bank produces operational summaries which can be measured against the progress of quarterly reports. At the time of this writing, the reports suggest that the project is still on pace to be completed by the end of 2020, suggesting a construction capacity of 10 kilometers of road per year.

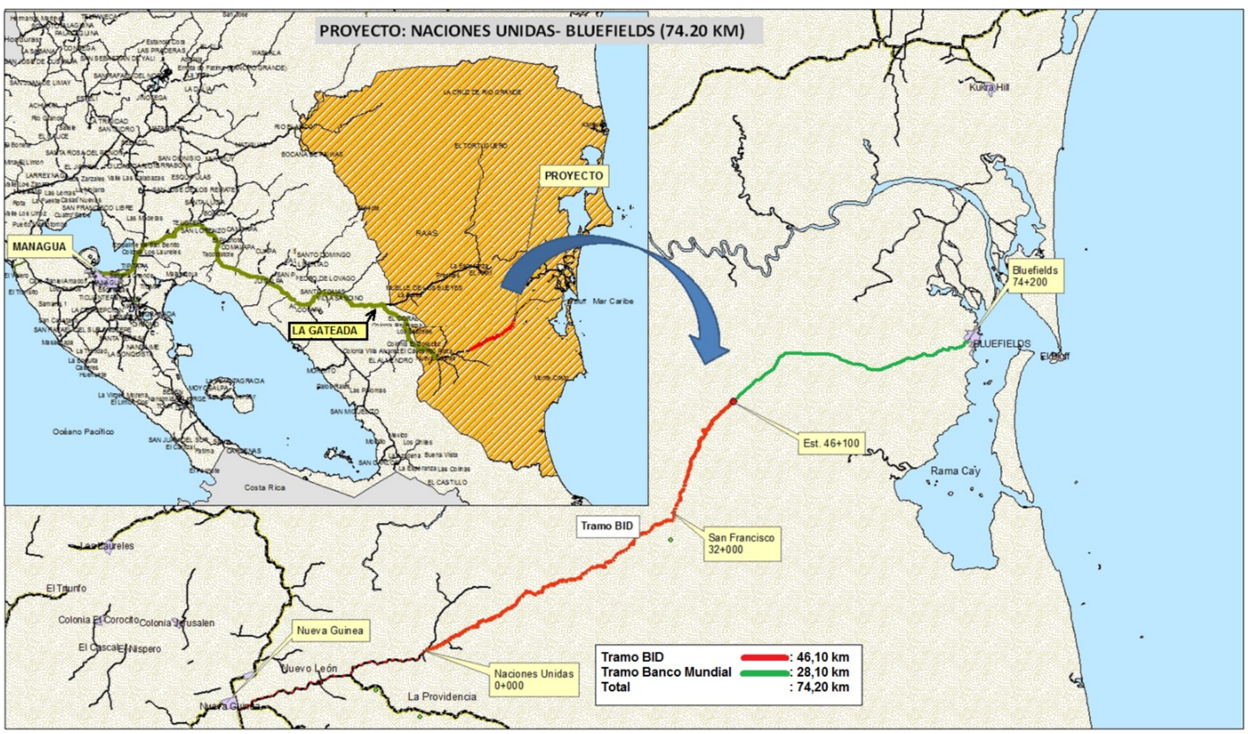

Figure 16. Proposed Inter-American Development Bank (2014) road route to connect Bluefields to the Nicaraguan interior.

Based on the aforementioned estimates for the length of each arc and mode as well as the infrastructure-expense estimates, a viable cost can be determined for each infrastructure leg within the proposed network. Table 3 gives the total anticipated expenses for the initial transportation infrastructure. It captures both the costs to construct the road and the alternatives for waterway and railway development.

Table 3

Anticipated expenses for the initial transportation infrastructure

Trip Leg	Distance (km)	Cost ($)
La Cruz de Rio Grande to Kukrahill via Pearl Lagoon communities	126	106,575,210
El Torugero to Kukrahill via Camp II Road	43	36,032,571
Pearl Lagoon to the Nicaraguan interstate system	9	7,611,300
Bluefields to Punta Aguila	62	52,800,000
Prinzapolka to Puerto Cabeza	101	88,000,000
Nueva Guinea to Bluefields	73	62,761,000
Total Road	**414**	**353,780,081**
Alternative 1: Waterway development to expand Rio Kukarawala to Rio Kurinwas (El Torugero)	15	60,000,000
Alternative 2: Railway from Bluefields to Punta Aguila	62	131,050,000

Parameter 1.3. Kilometers of each transportation infrastructure mode by year

$$\boldsymbol{KM_{it}}$$

In Table 4 are hypothetical estimates which assume that adequate resources are available and that there is a consistent supply of labor which is not involved with either local agricultural activities or canal construction. After Solver is run, the most efficient construction schedule will be developed based on cost and available resources. As a result, with the exception of one arc of the network, construction is pretty even across the five years. This evenly deployed construction model assumes that there are no stochastic events which could disrupt the building efforts. In addition, construction was split using this approach due to labor availability and the lack of travel means for one road at a time, e.g., constructing the La Cruz de la Rio Grande to Pearl Lagoon segment first; then, construction to other communities would not happen because laborers from the south or west would have no infrastructure to travel to the site. Therefore, each road is incrementally constructed using local labor pools instead of completing a road and moving on to the next project. In developed countries, this approach would not be utilized, but given the lack of infrastructure as well as travel means, incremental, simultaneous construction of each road is more likely.

Table 4

Hypothetical construction schedule prior to running solver

Year 1

Trip Leg	Distance (km)
La Cruz de Rio Grande to Kukrahill via Peal Lagoon communities	25
El Torugero to Kukrahill via Camp II Road	8
Pearl Lagoon to the Nicaraguan interstate system	9
Bluefields to Punta Aguila	12
Prinzapolka to Puerto Cabeza	20
Nueva Guinea to Bluefields	15
Total Road	**89**
Alternative 1: Waterway development to expand Rio Kukarawala to Rio Kurinwas (El Torugero)	13
Alternative 2: Railway from Bluefields to Punta Aguila	12

Table 4. *Hypothetical construction schedule prior to running solver* (continued)

Year 2

Trip Leg	Distance (km)
La Cruz de Rio Grande to Kukrahill via Peal Lagoon communities	25
El Torugero to Kukrahill via Camp II Road	8
Pearl Lagoon to the Nicaraguan interstate system	0
Bluefields to Punta Aguila	12
Prinzapolka to Puerto Cabeza	20
Nueva Guinea to Bluefields	15
Total Road	**80**
Alternative 1: Waterway development to expand Rio Kukarawala to Rio Kurinwas (El Torugero)	13
Alternative 2: Railway from Bluefields to Punta Aguila	12

Year 3

Trip Leg	Distance (km)
La Cruz de Rio Grande to Kukrahill via Peal Lagoon communities	25
El Torugero to Kukrahill via Camp II Road	8
Pearl Lagoon to the Nicaraguan interstate system	0
Bluefields to Punta Aguila	12
Prinzapolka to Puerto Cabeza	20
Nueva Guinea to Bluefields	15
Total Road	**80**
Alternative 1: Waterway development to expand Rio Kukarawala to Rio Kurinwas (El Torugero)	13
Alternative 2: Railway from Bluefields to Punta Aguila	12

Table 4. *Hypothetical construction schedule prior to running solver* (continued)

Year 4

Trip Leg	Distance (km)
La Cruz de Rio Grande to Kukrahill via Peal Lagoon communities	25
El Torugero to Kukrahill via Camp II Road	8
Pearl Lagoon to the Nicaraguan interstate system	0
Bluefields to Punta Aguila	12
Prinzapolka to Puerto Cabeza	20
Nueva Guinea to Bluefields	15
Total Road	**80**
Alternative 1: Waterway development to expand Rio Kukarawala to Rio Kurinwas (El Torugero)	13
Alternative 2: Railway from Bluefields to Punta Aguila	12

Year 5

Trip Leg	Distance (km)
La Cruz de Rio Grande to Kukrahill via Peal Lagoon communities	26
El Torugero to Kukrahill via Camp II Road	10.6
Pearl Lagoon to the Nicaraguan interstate system	0
Bluefields to Punta Aguila	14.1
Prinzapolka to Puerto Cabeza	21
Nueva Guinea to Bluefields	13
Total Road	**84.7**
Alternative 1: Waterway development to expand Rio Kukarawala to Rio Kurinwas (El Torugero)	15
Alternative 2: Railway from Bluefields to Punta Aguila	14.1

Parameter 1.4. Discount Rate

$$\beta^t$$

The current discount rate prescribed by the Central Bank of Nicaragua is 5%. The formula will remain consistent with this amount.

Parameter 1.5. Time

$$\sum_{t=5}^{50}$$

There are a number of time-based scenarios that can be incorporated into the model in order to determine the best analysis with respect to a regional (RAAN and RAAS) return on investment. Using data from the United States, a viable time period for overall project cost and benefit can be estimated. For example, many U.S. projects have been privatized, e.g., the Indiana Turnpike, were 75-year agreements (Plumer, 2012). Similar agreements involving public-private partnerships are being considered in other states. In Latin America, public-private partnerships for toll roads have been as short as 15 years. In the early 1990s, Latin-American governments experimented with privatization in many economic sectors, including roads, seaports, airfields, hospitals, tunnels, etc. Many countries, such as Colombia, Argentina, and Brazil, enjoyed multi-billion dollar investments. The new infrastructure improved transportation options by air, sea, and road because travel times were decreased, enabling a smoother flow of goods and services. A majority of the investments were made by companies in Europe, notably Spain, and, to some degree, firms in the United States.

Given that the last major agreement for an extensive network was 75 years and that Latin-American public-private partnerships have been 15 or 25 years, a project with this scope will use a baseline of 50 years. Given a 5% Nicaraguan Central Bank discount, 50 years is a viable period due to expense, size, complexity, and other large projects in the Americas with agreements. On the surface, 50 years is a long time for a return-on-investment period, but because this project is major, one can assume that planners will use a model of this size. The least cost solution is independent of who pays for the transportation network.

Parameter 1.6. Regional economic activities that will contribute to freight type and estimated weights

$$Y_{hkijt} \text{ and } \sum_{j=1}^{6}$$

A major canal and/or transportation network will create many economic opportunities for the region. Given that the area is underdeveloped, it is highly unlikely that the RAAS and RAAN regions will deviate from existing commercial activities unless there is major foreign investment or a commodity discovery. Therefore, it is anticipated that six economic sectors will grow significantly as a result of new global supply chain potential and logistics capacity. Beef production is likely going to be the largest industry because much of the region depends on this sector for its economic well-being. Many historic examples have demonstrated that new cattle-ranching potential led to significant deforestation. Given the tropical nature of the wood, there will be a global market for forestry products, presenting growth in this sector. Nicaragua's Caribbean-coastal opportunities for growth in shrimp and fish harvesting will occur as well as basic crop growth. The area will not create large crop exports given the soil types, but there will be some export beyond domestic consumption.

Parameter 1.6.1. Manufacturing

With or without the canal, it is anticipated that the $50 billion canal or a large-scale transportation investment, along with an inexpensive labor pool, will lead to the development of both free-trade zones as well as large-scale agricultural processing and storing centers. Following the construction of both the Panama and Suez Canals, large free-trade zones followed because of the ability for multinational corporations to take advantage of no or low import taxes on raw material, cheap labor, the ability to store large amounts of material, and no or low taxes on exports of finished product. Without a canal, Bluefields, as the critical node in the region, will be the main value-added processing center. Quantifying what manufacturing inputs are required is difficult; however, the General Authority for Investments and Free Trade Zones of Egypt (2017) does quantify what each facility would likely cost to construct. For example, at the Free-Trade Zone of Nasr City, it is estimated that the average facility used to manufacture textiles, process foods, or create clothing employs approximately 160 people; is about 3,000 square meters in size; and costs approximately $3.5 million. Although several million dollars seems like a significant cost, this price is attractive given the large savings on labor costs for manufacturing and warehousing.

Increased production at small and medium manufacturing facilities in the Bluefields area will be determined by several major factors: cattle processing and preparation for export, seafood processing and preparation for export, crop and forest-product preparation for export, and light manufacturing. Based on lessons learned from Egypt and Haiti, the free-trade zone should encourage foreign direct investment while ensuring that business opportunities for local companies and suppliers exist; in addition, technical links should be established between local suppliers and companies that make larges investments in zone infrastructure. With a canal, Bluefields will offer proximity to the deep-water port at Punta Aguila, an urban environment with a viable labor pool, and good international transportation connections to facilitate the zone's growth.

Estimated freight moved as a result of light and medium, non-agricultural-related manufacturing should resemble that of Port Said in Egypt. Data from Haiti were difficult to ascertain, but it was estimated that, in the aggregate, freight from free-trade zones is similar given the amount of employment reported. According to the Egyptian government, Port Said handled 3.4 million tons in its manufacturing zones in 2015 (Embassy of Egypt, 2016). For this dissertation, it is assumed that the figures would be similar given the size and complexity of operations as well as the scope of what is typically manufactured in developing nations with access to large ports and free-trade-zone infrastructure.

Although 3.4 million tons of freight per year appears high in a region where there is very little manufacturing activity, there are a number of attractive of reasons why this amount will be low for the Nicaragua projects. With the investment of roads and a deep-water port at Punta Aguila, the autonomous regions will have an opportunity to capitalize on the infrastructure necessary to facilitate the construction of free-trade zones. Many nations in Latin America have created free-trade zones to encourage investment and job creation within their borders, even without a canal. In addition, Panama can be used a template that leverages the canal and its associated transportation infrastructure as a manufacturing and economic-development enabler. For example, the Colon Free-Trade Zone enjoys billions of dollars of commerce each year. This is not to suggest that the same scale of growth could be accomplished in Nicaragua; however, given the current limited economic activities, there is certainly opportunity for importing, storing, packing, manufacturing, assembling, and shipping goods throughout the world using local labor. At its peak, the Colon Free-Trade Zone was importing and exporting over $30 billion per year (United States Department of Commerce, 2017c). Changes in Chinese logistic models have reduced this level to about $24 billion, which is still a major job creator for the Panama City region.

Once infrastructure is constructed, Nicaraguan economic developers should look to nations such as Egypt and Haiti for more realistic guidance. Although there is an amazing amount to learn from the Panamanian experience with respect to global supply chain integration using its free-trade zone on the canal, it is more realistic to anticipate something much smaller in scale. In Haiti, all of the legal requirements to establish free-trade zones exist, yet the investment is not nearly as robust as the government hoped. Presently, there is only one free-trade zone that is operational, and it is in the north part of the country (United States Department of Commerce, 2017c). Primarily, small manufacturing exists in this zone; American apparel companies have created factories for clothing production. Although small scale, the zone creates jobs in areas that have been plagued by high unemployment and poverty rates. Because Nicaragua is the second-most impoverished nation in Latin America following Haiti, many of the same economic challenges exist along the Atlantic coast. As such, small-scale manufacturing, such as clothing production or activity involving low-skill labor, is likely in RAAS near Punta Aguila or Bluefields. This opportunity is in addition to livestock, fishing, and crop exports that are anticipated.

Once the free-trade market becomes more mature, it is quite possible that Nicaragua will entice foreign direct investment into a more sophisticated free-trade-zone network. This potential is why the estimate is similar to what is observed in the Suez Zone. Something akin to Egypt and what it has been able to accomplish is quite possible. According to the United States International Free Trade Administration, Egypt has developed 10 free-trade zones with a focus on economic-sector clusters to include automotive assembly and components, chemicals and petrochemicals, construction and building materials, textile and ready-made garments, agribusiness and food processing, home appliances and electronics, logistics and warehousing, and pharmaceuticals (United States Department of Commerce, 2017b). Given that Nicaragua has a large unemployed population, some workers could be educated to specialize in low-skill manufacturing in areas of concentration.

Panama provides the gold standard for a free-trade zone. In essence, the canal transformed and modernized the economy, and having a large import and export presence was a key economic enabler for the country. Jobs were created, enabling a middle class to develop, thrive, and educate children. With lifestyle changes, new industries and service requirements became the norm. In time, Nicaragua could benefit from a similar, albeit smaller scale, model of these successes, as observed in Egypt. Should growth not develop like it did in the Suez trade area, a situation similar to northern Haiti becomes much more likely.

Once a free-trade zone comes on line, moving 12-13 million tons of textiles and clothing, as well as value-added agricultural products, from facilities in Bluefields to Punta Aguila is quite possible. It is possible that several million tons of raw material may be imported to support these industries. Overall, given existing examples in nations with similar infrastructure, a total of 5 million tons of freight per year is possible once the industrial zone(s) is (are) up and running. This potential requirement for raw material will reduce the difficulty with inbound-container receipts offsetting an imbalance of shipping containers. In addition, like the transport network, 5 years is a viable assumption for constructing the facilities which will be used to support global free-trade activities.

With any major transportation infrastructure, transportation investment, and growth, light-manufacturing opportunities will present themselves. Given its size and proximity to the proposed deep-water port at Punta Aguila, Bluefields will assume the role as a free-trade zone where industrial parks will be constructed to accommodate low-skill-labor increases for exports. Lastly, given the region's economic activity, service jobs for a new middle class will emerge. There are also limitations for how much growth can and will occur in response to new infrastructure, especially if no canal is built. For example, the deep-water port at Punta Aguila is likely to be constructed with a canal; without a canal, expansion may occur at Bluefields if economic activity is commensurate with investment requirements.

A few real-world examples exist, adding credence to the estimated 12-13 million tons of cargo that will move each year. According to the Embassy of Egypt (2016) in Washington, DC, the recent and planned upgrades to the Suez Canal will result in the development of cutting-edge commercial centers. At Ain Sohkna and East Port Said, there are plans to develop tens of thousands of hectares of land into industrial centers which can accommodate light, medium, and heavy manufacturing for a variety of products. Like Panama, companies can enjoy tax benefits by importing raw goods and materials into the zone, process the materials into finished products, and export the items from the zone. Nations such as Panama and Egypt benefit from the tremendous job growth that these designs bring. In Egypt, for example, it is estimated that over 200,000 jobs will be created in Ain Sohkna and East Port Said (Embassy of Egypt, 2016). New construction will expand the ports into large-scale manufacturing centers for transnational companies which are searching for a more-competitive tax environment; with Nicaragua, however, the primary economic activity will likely be concentrated around Bluefields with products being shipped to the Punta Aguila deep-water port. Infrastructure such as roads, homes for families, and a variety of secondary and tertiary growth will ensue as a result of new job creation.

In Haiti, it is estimated that approximately 30,000 jobs were created in its free-trade zones. Many American companies, such as Gap, Walmart, Target, Levi's, Hanes, etc., have established large assembly factories over the last several decades (United States Department of Commerce, 2017b). Haiti's proximity to southern ports in the United States, its relationship with the United States, and inexpensive labor (averaging $8 per day) enabled many clothing companies to establish a presence and to take advantage of special tax agreements. Most movements would occur via Bluefields as a transshipment point/critical node where rail or trucks would load and transport cargo, some via twenty-foot equivalent (TEU) units, to the deep-water port at Punta Aguila.

Parameter 1.6.2. Forestry

To determine anticipated freight using the reforestation estimate from Climate CoLab for the Nicaraguan autonomous regions, it is estimated that 400 trees will be deforested for each hectare (Esteli, 2012). In researching the average weights of trees in Central America and the Brazilian Amazon, one ton per tree is utilized as an assumed weight. In addition to weight, each municipality is examined and analyzed for potential economic activity and the propensity for additional deforestation given what is projected. These figures are solely estimates but provide a viable approach using regional data, economic trends, and projected average weights to determine what one could expect as far as lumber harvesting and transportation requirements are concerned. It is also important to note that these estimates are on the high side because they capture both the constraint of land-use changes and the likelihood that most municipalities will maximize logging opportunities during the study period. The total estimated number of logs which weigh 1 ton, on average, that will be cut and prepared for domestic or international use is 780,799,600. This is an estimate and can easily increase or decrease depending on the political situation in the country.

Table 5

Assumed deforestation by municipio

Municipality	Land Area (Hectares)	Projected Deforestation (%)	Hectares Deforested	Log Quantity for Export	Additional Information
Bilwi (RAAN)	598500	15	89775	35,910,000	Bilwi municipality encompasses Puerto Cabezas; most area is urban so periphery will be most impacted
Bonanza (RAAN)	203900	10	2039	815,600	Bonanza is not located in prime ranching country and is primarily located within the nation's extensive nature reserve system. As a result, it is unlikely that large scale deforestation will occur as a result of new logistics and supply chain opportunities
Mulukuku (RAAN)	190500	50	95250	38,100,000	Located near several nature reserves, Mulukuku has an abundance of forest that is likely to be harvested given cattle ranching activities and fewer protections; as such, this area will be on the high end of deforestation projections
Prinzapolka (RAAN)	702000	5	35100	14,040,000	This area is located in a major marsh and is primarily dependent on the fishing industry. As such, little or no deforestation is anticipated
Rosita (RAAN)	441800	20	88360	35,344,000	This area has already been devastated by intense deforestation efforts to support the mining industry. It is estimated that if additional supply chain capacity were to become available, this community would deforest the little remaining area given the high unemployment rate
Siuna (RAAN)	504000	30	151200	60,480,000	Some deforestation would occur here but a well endowed agroforestry research program coupled with extensive micro farming in cattle and beans would likely prevent large scale destruction
Waslala (RAAN)	133000	50	66500	26,600,000	Prime cattle ranching region with a heavy dependence on beef production; additional demand would lead to supply growth
Waspam (RAAN)	934200	50	467100	186,840,000	This area is highly impoverished so the potential development of cattle ranching and forest harvesting would likely lead to extensive deforestation due to economic necessity
Bluefields (RAAS)	477500	10	4775	1,910,000	Located in marsh land and already urbanized, it is anticipated that there may be deforestation activity on the periphery
Bocana de Paiwas (RAAS)	237500	50	118750	47,500,000	Prime cattle ranching region with a heavy dependence on beef production; additional demand would lead to supply growth

Table 5. *Assumed deforestation by municipio* (continued)

Municipality	Land Area (Hectares)	Projected Deforestation (%)	Hectares Deforested	Log Quantity for Export	Additional Information
Desem. Cruz de Rio Grande (RAAS)	197800	50	98900	39,560,000	Prime cattle ranching region with a heavy dependence on beef production; additional demand would lead to supply growth
El Ayote (RAAS)	83100	50	41550	16,620,000	Prime cattle ranching region with a heavy dependence on beef production; additional demand would lead to supply growth
El Tortugero (RAAS)	247100	50	123550	49,420,000	Prime cattle ranching region with a heavy dependence on beef production; additional demand would lead to supply growth
El Rama (RAAS)	561800	50	280900	112,360,000	Prime cattle ranching region with a heavy dependence on beef production; additional demand would lead to supply growth
Kukra Hill (RAAS)	126200	25	31550	12,620,000	Although somewhat dependent on cattle ranching, Kukrahill will experience less deforestation due to its proximity to the Reserva Natural Cerro Wawahan, tree types available for harvesting and neighboring marsh.
La Cruz de Rio Grande (RAAS)	336000	50	118000	47,200,000	Prime cattle ranching region with a heavy dependence on beef production; additional demand would lead to supply growth
Laguna de Perlas (RAAS)	387600	5	19380	7,752,00	With the exception of a few very small operations, this area is 1) in a marsh and 2) heavily dependent on tourism and fishing; as such, little to no additional deforestation is anticipated.
Muelle de los Bueyes (RAAS)	139100	50	69550	27,820,00	Prime cattle ranching region with a heavy dependence on beef production; additional demand would lead to supply growth
Nueva Guinea (RAAS)	277400	50	138700	55,480,000	Prime cattle ranching region with a heavy dependence on beef production; additional demand would lead to supply growth
Total	**6779000**		**2040929**	**780,799,600**	

Parameter 1.6.3. Cash Crops

In the RAAS province, farms are very small, and export opportunities are limited. This area is more likely to have cattle-production increases in the central and western sections of the province, whereas in the east, the land is suitable for sustenance farming with some opportunities for the growth and expansion of crops such as pineapples, breadfruit, and coconuts. The RAAN region, however, offers a very different opportunity. Chocolate consumption has increased, largely due to Chinese consumption. Nicaragua has an estimated 1.9 million hectares of land suitable for cocoa production in the RAAN region; presently, only 11,000 hectares of land are being used to grow the fruit (World Bank, 2014). According to the World Bank, Nicaragua is able to produce a quality, organic product much less expensively than Brazil can.

Concerning the export amount that is likely to be created, it is estimated that 2,750 tons of cocoa would be cultivated and exported (Cacaooro Nicaragua, 2018). For perspective, Ghana and the Ivory Coast produce 800 pounds per hectare, and Indonesia produces about 1,600 pounds per hectare. Assuming 1,000 pounds per hectare and only using 5,500 hectares (half of the available land based on the 50% land-use constraint which was introduced), almost 3,000 tons of the product will be farmed. Other scenarios could increase or decrease the number because land-use changes may not be enforced or because prices may, one day, be subdued, resulting in fewer opportunities for cultivation and export. Other crops will be consumed locally based on nutrition needs and diets of families in the region.

Parameter 1.6.4. Beef

If transportation infrastructure were to be constructed, economic activity, especially beef production in the RAAN and RAAS regions would expand substantially. It is anticipated that there would be some level of deforestation based on historic trends, easy money, access to resources, and the desire to expand cattle operations. If accomplished responsibly and sustainably, ranchers and lumber producers could all benefit for years to come. In 2002, Nicaraguan dairy exports totaled $5 million; a decade later, the exports exceeded $178 million (Cajina 2013); this estimate is with existing infrastructure and 70% of milk not accessing the market. If there were transportation options in place to enable larger exports and domestic-product use, the industry could grow very quickly. With additional ranches online, dairy opportunities could grow and create more jobs and economic opportunity. Societally, more people would have access to less-expensive milk and beef due to economies of scale and reduced transportation/logistics expenses. Increased nutrition intake would also reduce the strain on an unsophisticated health network because people would be healthier and better equipped to mitigate the effect of illness.

The same infrastructure and supply chains could be leveraged for beef production. In RAAN, RAAS, and central Nicaragua, over 100,000 people are directly employed by this sector; over 750,000 individuals are dependent on income from cattle. Therefore, having a sustainable market with growth potential could propel many families into better financial positions, enabling other economic activity and improving the domestic economy as a whole. The secondary effect, e.g., in the service industry, would benefit people who would spend incomes that did not exist prior to the transportation transformation.

If adequate transportation investments occurred, it is likely that funding for logistics activity would come to fruition shortly thereafter. Due to a lack of income and access, Nicaraguans only consume only 6 kilograms of beef per year (Schütz, P., Balsevich, F., & Reardon, T. A. 2004). Most of the beef is purchased through local markets, as opposed to grocery chains, creating challenges for refrigeration and freshness. To add complexity, most cattle are sold to butchers who use municipal slaughterhouses to process meat; unfortunately, many of these facilities lack the minimal equipment to ensure hygienic treatment of the product, and only a few are actually inspected by the Ministry of Agriculture (Shütz et al., 2004). The beef-production growth potential is highly subdued because the requisite transportation-and-logistics (refrigerated distribution centers and markets with adequate cooling capacity) network does not exist.

If road networks were constructed, cattle ranching would grow; industrial processing centers would likely follow with the appropriate cooling requirements to meet the new supply capacities. Put simply, there would be a business case for investors to contribute to the overall regional growth given the potential for high returns on investment. There is a global supply, demand and market price for beef and dairy products that is independent of Nicaragua's domestic-production and consumption. The potential for the RAAN and RAAS regions to leverage the direct and indirect economic benefits associated with beef and milk production simply requires infrastructure because the land, climate, and conditions are in place to produce below world prices. Given how well small and medium-sized operations have performed since 2002, it is suspected that cattle ranching offers the greatest potential for agricultural growth in the country's humid region.

With respect to growth for cattle ranching and milk production, however, it is critical that environmental needs are balanced with the economic-growth requirements. In addition, given that a majority of the crops which are suitable for the region will not require deforestation, the additional land made available for cattle ranching should be limited to no more than 20% in most areas with room for up to 50% in others. Although this number appears to be drastically high, historic precedence in places with similar climates and socioeconomic situations indicates that, without controlled growth and opportunity for local farmers, additional deforestation and damage to the ecosystem could occur if not offered and enforced by the Nicaraguan authorities. It is assumed that deforestation would be higher than 50% if adequate economic development opportunities are not afforded given insufficient resources to regulate this activity. Therefore, it is recommended that adequate opportunity be given to cattle ranchers and farmers in order to avoid deforestation akin to a nation such as Haiti or part of the Brazilian Amazon.

Cattle ranching will likely enjoy major expansion as a result of new transportation infrastructure in the RAAS and RAAN regions. Land-use changes, coupled with the ability to raise more cattle, will lead to massive growth and expansion for the industry. Nicaraguan beef follows a simple supply chain; for domestic consumption, the cattle is bread and sold to a stockholder where it is then transported to a municipal processing facility prior to going to market (Schütz et al., 2004). Presently, many of the municipal processing facilities in Nicaragua do not meet basic hygiene standards. If the domestic production of cattle and subsequent processing were to improve, significant investment in the domestic processing facilities would be required.

For international consumption, the supply chain requires a much more extensive and robust logistics network. The supply that is likely to follow as a result of land-use changes could double or even triple ranching production; therefore, investments need to be made along the supply chain. Like domestic consumption, a stockholder is likely to purchase cattle from the rancher although auctions are becoming more popular. From this point, the cattle are taken to industrial houses which meet the domestic and international standards for processing. The beef is processed; then, it is either transported to domestic markets via existing supply chains or exported via different distribution channels, usually to other Central-American nations such as Costa Rica and Honduras (Schütz et al., 2004). Like manufacturing's construction and infrastructure, a multi-million dollar investment would be required to facilitate the anticipated growth in the cattle industry in order to expand and to meet the international processing and production standards.

Determining growth in the beef-production markets is difficult given the many global dynamics that influence costs and decisions about whether to increase the livestock-production capacity; in 2017-2018, 325 million pounds of beef will be produced (Government of Nicaragua, 2017). Within the RAAN and RAAS regions, approximately 39% of the nation's total beef production occurs (Cajina, 2013), equating to 127 million pounds (63,500 tons) annually. If transportation infrastructure were to be funded, it is assumed that production would increase by 25-50% over the study period given cleared land near the existing livestock ranches along with investment for the processing capacity. If the Nicaragua canal is built, areas to the west of the autonomous region would likely increase capacity given the new export opportunities.

If the roads are constructed, a 37.5% increase in beef production (midpoint of estimate) is anticipated, equating to 87,313 tons. Should the canal come to fruition and if growth occurs in and around the RAAN and RAAS regions, it is assumed that beef production and freight requirements would increase to 156,400 tons. Of this amount, roughly half of the beef will be transported through the new network with the other half using the existing roads which connect to Managua. Therefore, 78,200 tons will move through the new network, with about 10% from the Pearl Lagoon area and the remaining regions dividing the traffic via new transportation-mode investments: e.g., 23,460 tons moving from Prinzapolka, Tortugeuro, and La Cruz de la Rio Grande. About 70% of the cattle ranching occurs in the area of focus and the surrounding political departments of Chontales, Matagalpa, Rio San Juan, and Boaco; these political departments will all experience growth commensurate with the RAAN and RAAS regions given the export demand and opportunities should the canal come online. It is also possible that milk production will increase with new investments in agriculture infrastructure. Should an increase happen, additional tonnage of freight will join beef; one could assume growth is highly possible given the dual use of cattle at most ranches.

Parameter 1.6.5. Seafood

With respect to production, almost 25,000 tons of seafood were caught and processed with approximately two-thirds of this activity occurring on or near the Caribbean coast (Food and Agricultural Organization of the United Nations, 2016). Given growth trends since 2000, it is quite possible that production could double, especially if farmed fisheries continue to develop at the current rate. With approximately 16,000 tons of production, up to 30,000 tons of product could move from farmed fisheries and wild-caught locations to processing facilities. This estimate is based on existing growth trends, available resources should road infrastructure and logistics networks strengthen, and a continued demand growth for the product. For this dissertation, about 25% will come from the Pearl Lagoon area, resulting in approximately 7,500 tons of seafood moving from the area into Bluefields. This assumes fish stocks are not constrained by biological limits or land use adjustments inland and can change should the constraints come to fruition.

Parameter 1.6.6. Amount supplied and its contribution to freight scenarios

For each variable, various scenarios are examined in order to determine the optimal expense and/or production level to maximize societal benefits. In addition, it is likely that constraints will be introduced for the production levels based on spillover effects. As such, each scenario captures a number of plausible outcomes based on historic production records, crop types, manufacturing potential, and the costs associated with transportation upgrades. To remain consistent with regional trends and historic production levels, research using nations such as Brazil and Belize as parallel examples is likely. These estimates is based on similar land-use changes, climate, industry, and infrastructure upgrades that are currently under consideration. In addition, for areas such as manufacturing, production rates in small and medium industries are used to determine production potential.

Parameter 1.7. Transportation mode types

$$\sum_{i=1}^{4}$$

For the purposes of this project, there is the potential for four transportation modes which are used to move the region's development forward. A majority of the infrastructure comes in the form of augmenting the existing road network. In addition to roads, the cost-minimization model determines if roads will be replaced by rail, waterway expansion, or fishing-boat infrastructure development. Descriptions for each transportation option were priced and outlined in the Methodology's network section.

Parameter 1.8. Length of each infrastructure mode constructed to meet the requirement to transport supplies from each origin to Bluefields

$$\sum_{(h,k)\in N}$$

Bluefields is the transportation network's central node. The choice to have Bluefield serve as the central node is due to existing infrastructure, the workforce, the city's current status as a hub, and the proximity to Punta Aguila where the deep-water port will be constructed to support the canal. Table 6 is a list of each infrastructure mode (Note that this is not the distance to Bluefields, but the distance to connect to either the existing road networks or the node) that will be built to accommodate the network's requirements.

Table 6

Length of each transportation arc

Trip Leg	Distance (km)
La Cruz de Rio Grande to Kukrahill via Peal Lagoon communities	126
El Torugero to Kukrahill via Camp II Road	42.6
Pearl Lagoon to the Nicaraguan interstate system	9
Bluefields to Punta Aguila	62.1
Prinzapolka to Puerto Cabeza	101
Nueva Guinea to Bluefields	73
Total Road	**413.7**
Alternative 1: Waterway development to expand Rio Kukarawala to Rio Kurinwas (El Torugero)	15
Alternative 2: Railway from Bluefields to Punta Aguila	62.1

Parameter 1.9. Cost of moving products from points of origin using different infrastructure types

$$C_{hkij}$$

To determine what it would cost to move freight across the RAAN and RAAS regions, it is important to note that the statistics pertaining to transportation expenses in Nicaragua were unobtainable; in general, the same principle pertained to the remainder of Latin America, especially with respect to the current and updated numbers. The United States Department of Transportation, however, does have data about the average freight revenue per Ton-mile in the United States. With the exception of labor, many of the inputs remain at or near constant because refined fuel, parts for vehicles, roads and locomotives, and other expenses are derived from developed world manufacturers. In the Overall, the costs per Ton-mile for transportation were as follows: $0.1654 for trucks, $0.0405 for rail, and $0.0183 for barges (United States Department of Transportation, 2014). When converted to kilometers, the updated rates per Ton-kilometer are as follows: $0.1028 for trucks, $0.0252 for rail, and $0.0114 for barges.

These average numbers pertain to U.S. transportation-shipping expenses, so there is likely some flexibility with respect to overall estimates; this is, however, among the best assumptions analyzed given the higher transportation expenses in Europe. Because there were very little data available for Latin America, these numbers are used to estimate freight-movement expenses per Ton-kilometer.

After capturing the cost to transport material using Tons-kilometer, the types of cargo, as well as estimated production over 50 years, were captured. Logging co-products, e.g., exportable lumber, were also annualized to ensure consistency for the period. From here, the total estimated tonnage for 50 years was multiplied by the cost per Ton-kilometer and then multiplied by the distance to determine estimated transport costs over a 50-year time period.

Table 7

Projected cost to move goods, by arc, over 50 years

Route and transport type	Product Type	Quantity Per Year (tons)	Total per year (tons)	Total over 50 years (tons)	Cost per Ton-km	Distance (KM)	Total Cost over 50 years ($)
Tortuguero to Kukra Road	Logs Beef	988,400 23,460	1,011,860	50,593,000	0.1028	42.6	$221,560,913
Tortuguero to Pearl Water Option	Logs Beef	988,400 23,460	1,011,860	50,593,000	0.0114	62	$35,759,132
Cruz de Rio Grande to Kukrahill Road	Logs Beef	791,200 23,460	814,660	40,733,000	0.1028	126	$527,606,402
Pearl to Bluefields fishing boat and barge	Logs Beef Seafood	155,040 7,820 7,500	155,040 7,820 7,500	775,200 391,000 375,000	0.0114 0.0114 12.28	38 38 38	$335,816.6 $169,381.2 $174,990,000
Pearl to Kukra Road	Logs Beef Seafood	155,040 7,820 7,500	170,360	8,518,000	0.1028	9	$7,880,854
Bluefields to Punta Aguila Road (using all logs from RAAN and RAAS due to deep-water port capacity)	Manufacturing Logs Beef Seafood	12,500,000 15,615,992 78,200 7,500	28,201,692	1,410,084,600	0.1028	62.1	$9,001,810,876
Bluefields to Punta Aguila Rail (using all logs from RAAN and RAAS due to deepwater port capacity)	Manufacturing Logs Beef Seafood	12,500,000 15,615,992 78,200 7,500	28,201,692	1,410,084,600	0.0252	62.1	$2,206,669,592
Prinzapolka to Puerto Cabeza Road	Logs Beef Cocoa	280,800 23,460 2,750	307,010	15,350,500	0.1028	101	$159,381,171

3.5. Overall Costs may not be Captured in the Model

3.5.1. Economic Benefits and Costs to RAAN and RAAS Regions with Transportation Infrastructure

Constructing a road system with or without building the canal is a requirement for Nicaraguan economic sectors to grow and develop. It is important to understand how the region will be transformed as a result of the new road network given the need to quantify the benefits associated with transportation investments. In addition, although minimizing transportation costs is the focus of the project, understanding how logistics networks will be transformed in the region is critical for the success of economic- and community-development efforts. Furthermore, public good can be achieved through additional export capacity for natural resources, such as timber and other agricultural products. In addition, it is safe to assume growth in livestock production and seafood harvesting as well as to anticipate the development of free-trade zones in order to accommodate new opportunities created as a result of the canal and its associated infrastructure. Not all benefits will be positive, so it is important to capture the unintended negative consequences. Using historic examples in regions with similar economic models and climate will highlight what one can anticipate in response to modernization.

3.5.2. Societal Costs as a Result of Land Use Adjustments

Megaprojects have the propensity to completely change the face of cities; regions; or, perhaps, nations and, over time, to create social change as a result of environmental adjustments; economic opportunities; and, sometimes, governance. The Nicaragua Canal is certainly a project with the potential to encourage many changes, both positive and negative. In addition, the associated transportation infrastructure beyond the new maritime shipping lane will increase the propensity for many costs, including societal ones. Having new economic prospects and opportunities in place may not only lead to modernization, but also encourage a rapid transition into a new social paradigm; this transition could be instigated by hasty land-use changes versus a gradual process. Unfortunately, given the nature of the canal project, as soon as adequate funding is in place, it likely that construction will begin immediately, inspiring the Nicaraguan government to move on supporting projects, e.g., Atlantic Road Connectivity and the investment in new free-trade infrastructure.

Given the major assumption of land-use change in this model, revisiting the transition based on regional parallels is necessary. According to Lambin and Meyfroidt (2011), developing countries experience four mechanisms of societal adjustments as land-use change occurs with globalization and economic integration; these steps are displacement, rebound, cascade, and remittance. In essence, a large population could be relocated as a result of this project, not forcibly by the government but by land-use changes and economic necessity. It is very unlikely that Nicaragua would follow suit when compared to Haiti where 98% deforestation occurred over a century; however, following the example of the Brazilian Amazon and Belize provides clues about what is likely to occur next.

Belize and Brazil experienced serious land-use adjustments as a result of globalization. In Brazil’s experience, converting rain forest into land which was suitable for crop development and ranching led to intense deforestation in the Amazon. As a result, Brazil lost approximately 20% of its pre-1970 forest coverage (Weinhold, D., & Reis, E. 2008). Unfortunately, spillover effects are difficult to quantify because society bears the brunt of the negative effects. Positive outcomes were relatively easy to quantify given the economic-development prospects associated with the canal project and the associated influence on transportation, logistics, and supply chain networks. Regarding the negative costs to society, one could anticipate the following:

3.5.2.1. Air-Quality Degradation

In nations where heavy deforestation occurs, health problems ensue as a result of poor air quality. Belize is considered one of Latin America's most effective land stewards; compared to its neighbors, Belize has regulated and prevented deforestation more effectively. However, the country has experienced additional pollution as a result of new transportation routes where fossil fuels are burned at higher rates and fewer trees absorb the carbon dioxide. As a result, some communities, especially in areas where high deforestation occurred (as much as 13,000 acres per month during its peak) have observed declines in health. It is too early to determine if life spans have declined in certain communities as a result of air-quality challenges. In addition, healthcare costs could increase as more treatment is required to treat diseases from polluted water or respiratory conditions caused by the reduced air quality.

3.5.2.2. Ecosystem Impact

If a transportation network is constructed as a result of the new canal, many of Nicaragua's bio preserves and ecosystems are likely to be negatively affected. The HKND Group claims that the management of the preserves will likely improve as a result of the project (HKND Group, 2014). According to the project's master plan, new job opportunities and economic-development prospects will result in less of a desire to deforest the region's protected lands. According to the project document, there will be a disincentive to deforest the area, and the canal's route is based on the smallest effect on nature possible. Canal construction aside, the corresponding road network would run through the following preserves: Indio Maiz Biosphere Reserve, Cerro Silva Natural Reserve, Blufields Wetlands, and a chain of reserves along the country's Mesoamerican Biosphere Corridor, leading to some level of environmental degradation, e.g., runoff from vehicle traffic, deforestation, air pollutants, inability of local or federal authorities to regulate, etc.

3.5.2.3. Watershed Pollution

There are several major rivers in addition to thousands of tributaries that create the RAAN and RAAS watershed network. A large portion of this water network is actually used as a transportation system. El Rama, a major city in the center of the RAAS region, is effectively an inland port that serves as a trade center given its geographic location. Like the ecosystem effect, it is very likely that new transportation activity, soil-quality declines due to deforestation, and other factors could lead to poorer water quality for the region. For many people, fishing this river network is a way of life that goes back centuries; many individuals' livelihoods could be negatively affected due to the change in water quality.

3.5.2.4. Sustainable Timber

It is possible that deforestation could result in foregoing future profits and use from sustainably harvested timber; this is due to the inability to regrow forests in a reasonable time frame. After the areas are deforested, ranching operations are likely to immediately follow, given the patterns in other Latin-American countries with similar climate, geography, and socioeconomic conditions. These patterns could also have an opportunity cost on sustainable forestry-related product development, e.g., toilet paper and paper towels.

3.5.2.5. Fire Suppression

Deforestation may affect nature's ability to manage fires. Natural environmental cycles lead to fires that burn underbrush and areas that require rectification; however, the purposeful adjustment of land use could result in the Nicaraguan government spending money in areas such as fire mitigation, suppression, and protection. In the western United States, it has become clear that poor forestry management in certain regions has led to large wildfires which should have been much smaller or contained.

3.5.2.6. Tourism Impact

Eastern Nicaragua enjoys a great deal of environmental tourism. Although a majority of tourism is concentrated in areas such as the Corn Islands, there are tours and jobs which have been created to serve tourists in the nature and biospehere reserves of both the RAAN and RAAS regions. If sufficient damage occurs, there is the potential for some of this tourism to be lost.

These examples of unintended consequences are a few of the costs to society that could come to fruition if the land-use policy is not properly developed and if lessons learned from the region are not adopted and implemented. Fortunately for the Nicaraguan government, there are many areas which could be improved and policies/practices sustained as a result of lessons learned from nations that experienced land-use changes, rapid development, and the incorporation of new transportation networks into daily life. In lieu of simply accepting the consequences, the central government in Managua could research and adopt best practices through effective legislation and regulation.

This element of the dissertation is captured as a qualitative augmentation about what is likely to occur as a result of the canal project with roads or simply a major investment in transport capacity for the autonomous regions. As more goods and services become exportable and accessible, it is likely that environmental degradation will occur based on opportunity and a desire for entities to enlarge their operations, e.g., cattle ranchers wishing to acquire more livestock and to sell to markets in Nicaragua that are now accessible via roads or abroad should additional supply chain channels open and mature.

3.5.3. Energy

The energy variable focuses on total vehicular and railway energy usage from Bluefields to Punta Aguila. This dissertation's assumption is that Bluefields will not only remain the commercial hub for the RAAS region, but will also adopt a similar function for the RAAN region and other areas to the west of the RAAS and RAAN regions. As road capacity is developed leading into Bluefields, it is safe to assume that logistical-support mechanisms and the associated infrastructure for new industry will be constructed and deployed in Bluefields. Although currently a city with 50,000 residents, its proximity to the site slated for a deep-water port at Punta Aguila makes it the logical choice to become the commercial hub. Because most processing capacity, to include some elements of free-trade activity, will be established in Bluefields, this dissertation focuses on the construction costs as well as the long-term operational and maintenance costs, to include the use of energy, of either a multi-lane highway from Bluefields to Punta Aguila or a railway that can accommodate the region's anticipated export capacity.

After the information was collected and researched, it was placed into Excel Solver. Various scenarios were run within Solver, yielding the results in Chapter 4.

CHAPTER 4. FINDINGS AND DISCUSSION

The main goal of this research is to determine the minimum cost of developing a multimodal transportation network in the RAAS and RAAN provinces which will enable the movement of goods and services as well as supporting economic and societal development. From there, a number of other important questions surfaced regarding the network: what will the minimum costs be for various transportation options in the region; what triggers will determine if a railway should be built versus a 10-ton road infrastructure with an emphasis on Bluefields to Punta Aguila; what triggers will determine if river transportation should be expanded versus a 10-ton road infrastructure with an emphasis on interior rural communities; what triggers will determine if fishing boats on the Caribbean coast should make additional investments versus additional road infrastructure in order to move seafood to Bluefields for consumption and processing for export?

4.1. Data Analysis

The purpose of this research was to determine the minimum cost associated with constructing and deploying a transportation network in the RAAN and RAAS provinces of Nicaragua. Based on the model, the least-costly solution was a multimodal network that took approximately 5 years to construct. The total cost over a 50-year period, including initial construction expenses, operations and maintenance, and the cost to move goods across the network, came to $861,419,624.87. This includes $455,997,512.87 in initial capital construction investment and $405,422,112 for vehicle operation and road system maintenance over 50 years. For perspective, the Nicaraguan Ministry of Transport and Infrastructure (MTI) requested a budget of $168,300,000 for 2019; this amount included approximately 200 kilometers of new road construction and links (MTI, 2018). Combined with the Inter-American Development

Bank's budget for the Atlantic Road Interconnectivity Project, a project of this magnitude would require all domestically allocated highway resources for the 5-year period.

In addition to the $861 million cost for the multimodal network, the model presented a construction schedule that did not correlate with the estimated building pace. This disconnect is likely due to limited financial and personnel resources which are manifested in the constraints as well as the mode types prescribed by the model. Overall, the initial cost data for the network were $861,419,624.87 over 50 years with a 5% discount rate. With respect to when the roads would be built and the modes connected, Solver yielded the results shown in Table 8.

Table 8

Number of kilometers of road constructed and cabildo connection using all modes

Year	**Sum of KM**		
1	0	<=	100
2	28	<=	100
3	100	<=	100
4	100	<=	100
5	100	<=	100
Cabildo			
Tortuguero	1	=	1
Cruz de Rio Grande	1	=	1
Pearl	1	=	1
Bluefields	1	=	1
Prinzapolka	1	=	1

Table 9 gives an indication about the weight (in tons) of product moved across the network on an annual basis. This particular constraint assisted with determining which modes were used to transport goods. It is important to note that the network can support the supply of each commodity type originating from the *cabildos* which are included in the network.

Table 9

Type and weight of shipments by origination point annual data

New Y Constraint			
Tortuguero logs	988,400	=	988,400
Tortuguero beef	23,460	=	23,460
Cruz logs	791,200	=	791,200
Cruz beef	23,460	=	23,460
Pearl logs	155,040	=	155,040
Pearl beef	7,820	=	7,820
Pearl seafood	7,500	=	7,500
Blue manufacturing	12,500,000	=	12,500,000
Blue logs	15,615,992	=	15,615,992
Blue beef	78,200	=	78,200
Blue seafood	7,500	=	7,500
Prinza logs	280,800	=	280,800
Prinza beef	23,460	=	23,460
Prinza cocoa	2,750	=	2,750

Decision variables about what modes would be constructed during each year, including the length of each arc by year, are shown in Table 10.

Table 10

Construction years and length including each mode

Arc	Mode	Year	KM
Tortuguero to Kukra road	Road	1	0
Tortuguero to Pearl water option	inland water	1	0
Cruz de Rio Grande to Kukrahill road	Road	1	0
Pearl to Bluefields barge	inland water	1	0
Pearl to Bluefields fishing boat	ocean water	1	0
Pearl to Kukra road	Road	1	0
Bluefields to Punta Aguila road	Road	1	0
Bluefields to Punta Aguila rail	Rail	1	0
Prinzapolka to Puerto Cabeza road	Road	1	0
Tortuguero to Kukra road	Road	2	0
Tortuguero to Pearl water option	inland water	2	0
Cruz de Rio Grande to Kukrahill road	Road	2	4
Pearl to Bluefields barge	inland water	2	24
Pearl to Bluefields fishing boat	ocean water	2	0
Pearl to Kukra road	Road	2	0
Bluefields to Punta Aguila road	Road	2	0
Bluefields to Punta Aguila rail	Rail	2	0
Prinzapolka to Puerto Cabeza road	Road	2	0
Tortuguero to Kukra road	Road	3	0
Tortuguero to Pearl water option	inland water	3	15
Cruz de Rio Grande to Kukrahill road	Road	3	85
Pearl to Bluefields barge	inland water	3	0
Pearl to Bluefields fishing boat	ocean water	3	0
Pearl to Kukra road	Road	3	0
Bluefields to Punta Aguila road	Road	3	0
Bluefields to Punta Aguila rail	Rail	3	0
Prinzapolka to Puerto Cabeza road	Road	3	0
Tortuguero to Kukra road	Road	4	0
Tortuguero to Pearl water option	inland water	4	0
Cruz de Rio Grande to Kukrahill road	Road	4	37
Pearl to Bluefields barge	inland water	4	0
Pearl to Bluefields fishing boat	ocean water	4	0
Pearl to Kukra road	Road	4	0
Bluefields to Punta Aguila road	Road	4	0
Bluefields to Punta Aguila rail	Rail	4	0
Prinzapolka to Puerto Cabeza road	Road	4	63
Tortuguero to Kukra road	Road	5	0
Tortuguero to Pearl water option	inland water	5	0
Cruz de Rio Grande to Kukrahill road	Road	5	0
Pearl to Bluefields barge	inland water	5	0
Pearl to Bluefields fishing boat	ocean water	5	0
Pearl to Kukra road	Road	5	0
Bluefields to Punta Aguila road	Road	5	0
Bluefields to Punta Aguila rail	Rail	5	62
Prinzapolka to Puerto Cabeza road	Road	5	38

Unfortunately, none of the products officially move until year five. There will be informal movements like those which are accomplished today; however, weights as well as modes are articulated in Table 11 based on the network's construction and the integration points along the route.

Table 11

Weights and year as well as the mode indicating where goods move

Arc	Mode	Commodity	Year	Y
Tortuguero to Pearl water option	inland water	Logs	5	988,400
Tortuguero to Pearl water option	inland water	Beef	5	23,460
Cruz de Rio Grande to Kukrahill road	Road	Logs	5	791,200
Cruz de Rio Grande to Kukrahill road	Road	Beef	5	23,460
Pearl to Bluefields barge	inland water	logs	5	155,040
Pearl to Bluefields barge	inland water	beef	5	7,820
Pearl to Bluefields barge	inland water	seafood	5	7,500
Pearl to Bluefields fishing boat	ocean water	seafood	5	0
Pearl to Kukra road	Road	Logs	5	0
Pearl to Kukra road	Road	Beef	5	0
Pearl to Kukra road	Road	seafood	5	0
Bluefields to Punta Aguila road	Road	manufacturing	5	0
Bluefields to Punta Aguila road	Road	Logs	5	0
Bluefields to Punta Aguila road	Road	Beef	5	0
Bluefields to Punta Aguila road	Road	seafood	5	0
Bluefields to Punta Aguila rail	Rail	manufacturing	5	12,500,000
Bluefields to Punta Aguila rail	Rail	Logs	5	15,615,992
Bluefields to Punta Aguila rail	Rail	Beef	5	78,200
Bluefields to Punta Aguila rail	Rail	seafood	5	7,500
Prinzapolka to Puerto Cabeza road	Road	Logs	5	280,800
Prinzapolka to Puerto Cabeza road	Road	Beef	5	23,460
Prinzapolka to Puerto Cabeza road	Road	Cocoa	5	2,750

Concerning the required transportation construction, by highlighted arc in Chapter 3, each major construction leg and its respective details are listed in the following sections.

4.1.1. La Cruz De Rio Grande to Kukrahill via Pearl Lagoon

The model presented a road-construction solution for this arc. Solver proposed that construction begin in year two with 4 kilometers of road being constructed. This result differed from the year-by-year breakdown which was hypothesized based on perceived resources, such as manpower. In year three, the model suggested that 85 kilometers of road be constructed; when compared to the current IBD project for interconnectivity between Bluefields and the inland communities, it became clear that this task would be difficult based on the project's existing trajectory. If resources commensurate with the transportation network became available, effective planning and project management could enable this accelerated construction project to come to fruition. In year four, the results suggested another 37 kilometers of road construction, thereby completing the arc.

Although construction for this arc is completed in year four, the road itself will not be connected with the remainder of the network until year five due to the dependency of the remainder of the multimodal network. Although there is a probability that products will move on this road prior to year five, official movement through a fully functional and connected network does not begin until year five. During this period, it is expected that 791,200 tons of logs and 23,460 tons of beef will move through this arc on an annual basis in years 5-50. There is the likelihood that there will be inbound products which contribute to overall freight, but these numbers were not collected because the region must develop economically prior to speculating about the type of goods and services that people will demand within 25 kilometers of the *municipio*.

4.1.2. El Torugero to Kukrahill via Camp II Road

The model presented an inland-waterway solution for this arc. The model proposed that construction begin in year 3 with 15 kilometers of inland waterway being dredged and the appropriate infrastructure constructed. A road was assumed for this arc given its proximity to Camp II as well as access to the highway system. In addition, the recommended length and year prescribed by the solver differed from the year-by-year breakdown hypothesized with the perceived resources, such as manpower. As such, the El Tortugero to Kukrahill route varied in several ways from an assumed construction plan; for example, the inland waterway would facilitate travel to Pearl Lagoon and its environs versus the road network connecting to the highway system.

Although the inland waterway will be constructed by the end of year three, this arc will not be connected to the greater multimodal network until year five due to the arc's dependency on the project's Pearl Lagoon component. One should anticipate the movement of goods and services upon completion of the project, but official transport will not occur until year five. Collectively, over 1,000,000 tons of beef and logs will utilize this arc to access global markets with 988,000 tons of logs and 23,460 tons of beef. Therefore, this inland-waterway system will be very busy and will also have some level of backhaul/match back based on economic development in and around the *municipio*.

4.1.3. Pearl Lagoon to the Nicaraguan Road System

The model presented an inland-waterway solution for this arc. The model proposed that construction begin in year 2 with 24 kilometers of inland waterway being dredged and the appropriate infrastructure constructed. There were no assumptions for a road given the proximity to multiple water modes, include the use of fishing vessels, in order to move products to

Bluefields. What was interesting is that the proposal called for work to occur in year two, but given the proximity to the waterway from El Tortugero, this element would be the first construction phase of the two arcs, thereby lending personnel and equipment to second phase the following year. Given the movement of goods directly to Bluefields, this arc would also be connected to the broader network immediately.

Moving 155,040 tons of logs; 7,820 tons of beef; and 7,500 tons of seafood would not occur until year 5. Waiting until year 5 is likely due to the work connecting Bluefields to Punta Aguila which will be discussed later. It is practical to mention that logs, as well as other products, will likely move before year 5 given the adjustments which are likely to occur with the land use as well as current fishing that occurs with the fish transported via fishing trawlers to customers. As infrastructure comes online for processing in Bluefields and as the deep-water port is constructed, one could anticipate an increased and maximized flow of products originating from the Pearl Lagoon region.

4.1.4. Bluefields to Punta Aguila

The model presented a rail solution for this arc. The model proposed that construction begin in year 5 with 62 kilometers of rail. This timeframe is a challenge given the length of track as well as competing resources for road and inland-waterway construction in the region, so work on the tracks as well as the supporting infrastructure would have to occur prior to the track being built; this approach would ensure that the entire the network is up and running, assuming that there is a deep-water port at Punta Aguila. Given the reliance on a deep-water port to handle the export traffic, this particular node is critical for the entire network.

Given construction completion during year five, the entire network will be prepared to move products throughout the region. Bluefields is the primary recipient for all inbound goods.

This assumption is due to the ability to produce value-added agricultural products, to manufacture and package products, and to use raw materials to create local industry. There is an assumption that a free-trade zone will be established to encourage foreign direct investment. All products which are received and/or processed in Bluefields will head south to Punta Aguila and be transloaded at the planned port.

The total quantities of goods being moved from Bluefields to Punta Aguila in year 5 include 12,500,000 tons of manufactured products via the free-trade zone; 15,615,992 tons of logs; 78,200 tons of beef; and 7,500 tons of seafood. These quantities assume a mixture of raw materials as well as ones which have been processed.

4.1.5. Prinzapolka to Puerto Cabeza

The model presented a road solution for the Prinzapolka to Puerto Cabeza arc. This solution was the only proposed option and it was examined to determine the road's length and when it should be developed as part of the broader network. The model proposed that construction begin in year 4 with 63 kilometers of road being constructed; the remaining 38 kilometers are planned for year 5. This approach is more feasible than the network's other elements because Prinzapolka lies in the north and has a different labor pool than the work in the RAAS province will have. In addition, this arc would complete the northern alignment to the highway system that serves communities which connect to the provincial and national capitals.

Once this road is constructed, it is anticipated that it will begin moving products sometime during year 5 with estimates of 280,800 tons of logs; 23,460 tons of beef; and 2,750 tons of cocoa. There is a probability that the cocoa could be processed in the RAAN province at Puerto Cabeza or even in Managua given the existing supply chain and logistics networks.

Therefore, this particular product was not included in the estimate for moving through Bluefields but could change in the event that there were other forcing functions.

4.2. Sensitivity Analysis

In addition to the primary research question about determining the minimum cost of a multimodal network in the RAAN and RAAS regions of Nicaragua, it is important to note that, given the transportation-cost realities of Latin America, there are alternative cost scenarios for each arc of the network. Table 12 gives a few options that were considered for cost.

Table 12

Network costs using multiple configurations based on the regional data

Network-Cost Configuration	Network 50-Year Cost
U.S. per Ton-km (rail and truck)	$861,419,624.87
Nicaraguan trucking Ton-km	$993,539,139.35
Latin American rail Ton-km	$1,401,549,355.20
Nicaraguan trucking and Latin American rail Ton-km	$1,533,668,869.68

4.2.1. Given the Trucking Rate of $0.17, a Sensitivity Analysis was Conducted via the Model and Yielded the Following Results.

Although the model assumed less-expensive transportation rates commensurate with the costs associated with the United States due to a modern network and new equipment, the reality is that costs will likely reflect the existing operations in Nicaragua. One of the main reasons for this difference beyond using older vehicles, deferring maintenance, and having government-created inefficiencies is the restriction of trucks to lower-than-gross vehicle rates of 80,000 pounds. Per Figure 17, there are only two vehicle configurations that can meet the gross-vehicle rate comparison in the United States: T3-S3 and T3-S2.

Vehicle type	Element	Regional	CR	SV	GT	HN	NI	PA	DO
C2	Front axle	5.0	5.0	5.0	5.0	5.0	5.0	4.0	9.0
	Tractor axle	10.0	10.0	10.0	10.0	8.0	9.0	10.0	9.0
	Total	15.0	16.0	15.0	15.5	-	-	-	-
C3	Front axle	5.0	5.0	5.0	5.0	5.0	5.0	5.5	9.0
	Tractor axle	16.5	15.0	16.5	16.5	16.0	16.0	16.4	14.5
	Total	21.5	21.0	21.5	22.0	-	-	-	-
C4	Front axle	5.0	5.0	5.0	5.0	5.0	5.0	5.5	9.0
	Tractor axle	20.0	23.0	20.0	20.0	20.0	20.0	22.0	
	Total	25.0	29.0	25.0	25.0	-	-	-	-
T2-S1	Front axle	5.0	5.0	5.0	5.0	5.0	5.0	5.5	9.0
	Tractor axle	9.0	10.0	9.0	9.0	8.0	9.0	10.0	9.0
	Trailing axle	9.0	10.0	9.0	9.0	8.0	9.0	10.0	9.0
	Total	23.0	26.0	23.0	23.0	-	-	-	19.5
T2-S2	Front axle	5.0	5.0	5.0	5.0	5.0	5.0	5.5	9.0
	Tractor axle	9.0	10.0	9.0	9.0	8.0	9.0	10.0	9.0
	Trailing axle	16.0	16.5	16.0	16.0	16.0	16.0	16.4	14.5
	Total	30.0	32.5	30.0	30.0	-	-	-	27.3
T2-S3	Front axle	5.0	5.0	5.0	5.0	5.0	5.0	5.5	9.0
	Tractor axle	9.0	10.0	9.0	9.0	8.0	9.0	10.0	9.0
	Trailing axle	20.0	23.0	20.0	20.0	20.0	20.0	22.0	
	Total	34.0	39.0	34.0	34.0	-	-	-	30.1
T3-S1	Front axle	5.0	5.0	5.0	5.0	5.0	5.0	5.5	9.0
	Tractor axle	16.0	16.5	16.0	16.0	16.0	16.0	16.4	14.5
	Trailing axle	9.0	10.0	9.0	9.0	8.0	9.0	10.0	9.0
	Total	30.0	32.5	30.0	30.0	-	-	-	30.1
T3-S2	Front axle	5.0	5.0	5.0	5.0	5.0	5.0	5.5	9.0
	Tractor axle	16.0	16.5	16.0	16.0	16.0	16.0	16.4	14.5
	Trailing axle	16.0	16.5	16.0	16.0	16.0	16.0	16.4	14.5
	Total	37.0	39.0	37.0	37.0	-	-	-	30.1
T3-S3	Front axle	5.0	5.0	5.0	5.0	5.0	5.0	5.5	9.0
	Tractor axle	16.0	16.5	16.0	16.0	16.0	16.0	16.4	14.5
	Trailing axle	20.0	23.0	20.0	20.0	20.0	20.0	22.0	-
	Total	41.0	45.5	41.0	41.0	-	-	-	-
B-double		No	Yes	No	Yes	-	-	Yes	No

Figure 17. Maximum weights per vehicle type in Central America (IDB, 2014).

Given the change to $0.17 per Ton-kilometer, the minimum cost associated with constructing and deploying a transportation network in Nicaragua's RAAN and RAAS provinces over 50 years increased. The total cost for a 50-year period, including initial construction expenses, operations and maintenance, and the cost to move goods across the network, came to $993,539,139.35, approximately $130 million higher when compared to the initial model; this includes $455,997,512 in capital construction costs and $537,541,627 in to operate and maintain both the network and the vehicles to transport the goods over 50 years.

In addition to a network that costs approximately $1 billion to construct, operate, and manage in order to move products over a 50-year period, no major changes were discovered about which mode to construct or when arcs were connected, thereby enabling transport. As such, the same network recommendation using a cost-minimization model holds where most of the modes become operational for transport during year five. Following the initial linear program involving inputs and constraints, a sensitivity analysis which used costs more reflective of Latin-American trucking and rail was evaluated.

4.2.2. Given the Railway Rate of $0.0462, a Sensitivity Analysis was Conducted via the Model and Yielded the Following Results.

Although the model assumed less-expensive transportation rates commensurate with the costs in the United States due to a modern network and new equipment, the reality is that costs will likely reflect the existing operations in Nicaragua. There are several reasons that higher costs are likely. When analyzing 18 rail systems in Latin America, the tracks and equipment tend to be older, resulting in higher operational expenses. In some cases, maintenance expenses have been deferred; in others, state-owned enterprises offer inefficient and expensive rail operations. In both instances, there is very little competition (Organization for Economic Co-Operation and Development 2014). In the United States where seven Class I rail companies as well as hundreds of short lines compete for business, efficiencies as well as infrastructure investment are paramount to achieve profitability.

Given twice the cost for moving goods via rail when compared to rates in the United States, it was important to run Solver given that, during the 50-year period, all products are assumed to move from Bluefields to Punta Aguila if the deep-water port comes online. Over the 50-year period, the costs to build, manage, operate, and move goods across the network went from under $900 million to $1,401,549,355.20: over half-a-billion dollars more! When further broken down, this equates to $455,997,512 in capital investment to construct the network and $945,551,843 to operate and maintain the network and transportation fleet over 50 years. Interestingly, the network construction did not change, thereby retaining the same nodes as suggested during the model's first run as well as when transportation would begin to move goods across the network. Hopefully, a network that can incorporate cost-cutting incentives would reduce costs. Many networks in Latin America are antiquated with some being over 100 years old (although there have been upgrades).

4.2.3. With a Trucking Rate of $0.17 and the Train Rate of $0.0462, a Sensitivity Analysis was Conducted via the Model and Yielded the Following Results.

To gauge what it would cost to construct, manage, operate, and move goods throughout a network over a 50-year period using a trucking rate which was consistent with the cost per ton-kilometer in Nicaragua as well as an average of Latin-American railways, Solver was run. The estimated cost for this network would be $1,533,668,869.68, almost $700 million higher than the initial cost-minimization model using rates commensurate with the movement of goods in the United States. This equates to $455,997,512 in the initial infrastructure investment and $1,077,671,357 to operate and maintain the network and vehicles over 50 years. Therefore, this scenario is more likely due to more-appropriate comparisons and management models in the region. Also, it is important to note that the recommended mode, as well as when to move goods (primarily year 5), remained constant.

4.3. Additional Sensitivity Analysis

Beyond adjustments with the Latin-American rates for trucking and rail, it was important to examine the constraints and thresholds about where it would no longer be viable to use railways, roads, and inland waterways. As a result of this examination, the following scenarios were determined to ensure that a full spectrum of variable adjustments were tested.

4.3.1. Road-Construction Limits Per Year

The Inter-American Development Bank (IDB) intended to build approximately 15 kilometers of road per year within its Atlantic Connectivity Network project from Nueva Guinea to Bluefields. According to quarterly reports (IDB, 2018), by December 2018, local construction crews were building fewer than 10 kilometers of road per year. There were no specific indicators about why the construction was not occurring according to the engineering and design planning; however, for the purposes of designing the overall transportation network, there was an assumption that limited equipment, a lack of skilled labor, and resource constraints would result in the inability to build the network over five years. It is important to note however a longer period would be required to construct the network as the five-year build would create more conducive conditions for a Nicaragua canal project.

During the development of the linear program and subsequent modeling in Solver, it became evident that there was no ability to construct the network using a 10- or 15-kilometer road-construction limit per year. Solver would not run the model, so 100 kilometers became the new constraint based on the 5-year network-construction limit. Given the 5-year timeline, it was important to determine what the actual road-construction minimum would be. After several model runs, in order to meet the 5-year construction and deployment requirement, a minimum of 63 kilometers per year would have to be constructed. To meet this mandate, the RAAN and RAAS authorities will require external assistance. The help could come from firms descending on the area from other Nicaraguan regions as well as international companies. Equipment and personnel must be mobilized in the region.

Table 13

Minimum kilometers of road construction to meet the five-year requirement

Year	Sum of KM		
1	61	<=	63
2	63	<=	63
3	63	<=	63
4	63	<=	63
5	63	<=	63

In addition to adjustments for the number of road kilometers constructed per year in Table 13, it is important to note that the cost of the network's construction increased. The cost adjusted slightly more than $13 million due to an adjusted construction schedule, the cost to borrow money in order to finance the project during the 50-year period, and the time when goods can be transported across the network. The new cost for the network with the 63-kilometer assumption is $1,547,182,175.79

With the 63-kilometer per year road-construction limit, the network construction schedule changed. Construction began in year 1, whereas the 100-kilometer limit called for no construction in year 1. Construction during year 2 effectively doubled when compared to the original model as well, indicating that the network's road-construction element was much more evenly distributed. In the original model, most of the road construction occurred in years 4 and 5, whereas the length constraint forced additional distribution. This is demonstrated in Table 14.

Table 14

New suggested infrastructure-construction schedule based on the 63-kilometer constraint

Arc	Mode	Year	KM
Tortuguero to Kukra road	road	1	0
Tortuguero to Pearl water option	inland water	1	0
Cruz de Rio Grande to Kukrahill road	road	1	23
Pearl to Bluefields barge	inland water	1	0
Pearl to Bluefields fishing boat	ocean water	1	0
Pearl to Kukra road	road	1	0
Bluefields to Punta Aguila road	road	1	0
Bluefields to Punta Aguila rail	rail	1	0
Prinzapolka to Puerto Cabeza road	road	1	38
Tortuguero to Kukra road	road	2	0
Tortuguero to Pearl water option	inland water	2	0
Cruz de Rio Grande to Kukrahill road	road	2	63
Pearl to Bluefields barge	inland water	2	0
Pearl to Bluefields fishing boat	ocean water	2	0
Pearl to Kukra road	road	2	0
Bluefields to Punta Aguila road	road	2	0
Bluefields to Punta Aguila rail	rail	2	0
Prinzapolka to Puerto Cabeza road	road	2	0
Tortuguero to Kukra road	road	3	0
Tortuguero to Pearl water option	inland water	3	15
Cruz de Rio Grande to Kukrahill road	road	3	40
Pearl to Bluefields barge	inland water	3	0
Pearl to Bluefields fishing boat	ocean water	3	0
Pearl to Kukra road	road	3	0
Bluefields to Punta Aguila road	road	3	0
Bluefields to Punta Aguila rail	rail	3	8
Prinzapolka to Puerto Cabeza road	road	3	0
Tortuguero to Kukra road	road	4	0
Tortuguero to Pearl water option	inland water	4	0
Cruz de Rio Grande to Kukrahill road	road	4	0
Pearl to Bluefields barge	inland water	4	0
Pearl to Bluefields fishing boat	ocean water	4	0
Pearl to Kukra road	road	4	0
Bluefields to Punta Aguila road	road	4	0
Bluefields to Punta Aguila rail	rail	4	0
Prinzapolka to Puerto Cabeza road	road	4	63
Tortuguero to Kukra road	road	5	0
Tortuguero to Pearl water option	inland water	5	0
Cruz de Rio Grande to Kukrahill road	road	5	0
Pearl to Bluefields barge	inland water	5	0
Pearl to Bluefields fishing boat	ocean water	5	0
Pearl to Kukra road	road	5	9
Bluefields to Punta Aguila road	road	5	0
Bluefields to Punta Aguila rail	rail	5	54
Prinzapolka to Puerto Cabeza road	road	5	0

4.3.2. Adjusting the Discount Rate

According to the Central Bank of Nicaragua, the discount rate is 5%. As a result, the model used 5% over the network's 50-year lifespan. Unfortunately, discount rates can change based on inflationary factors or other political and/or economic factors. To understand if there were an effect if the rate changed, 15% was used to determine if major changes occurred. Once 15% was tested, the network's construction schedule was adjusted. For example, the recommended railway for the arc originating in Bluefields and going to Punta Aguila was slated for year 5 in the original model. After adjusting for a 15% discount rate, the network's rail component was moved to the first year of the project. Given equipment and resource constraints, it is unlikely that 52 kilometers of rail would be constructed; however, this mode was the model's suggested approach.

In addition to rail adjustments, the network's construction became more evenly distributed. It is also important to note that the discount-rate alteration occurred simultaneously with the 63-kilometer per year construction constraint; this is likely why there was closer to even distribution throughout the five-year build. Table 15 highlights the changes with a 15% discount rate.

Table 15

New suggested infrastructure-construction plan based on the 15% discount rate

Arc	Mode	Year	KM
Tortuguero to Kukra road	road	1	0
Tortuguero to Pearl water option	inland water	1	0
Cruz de Rio Grande to Kukrahill road	road	1	0
Pearl to Bluefields barge	inland water	1	0
Pearl to Bluefields fishing boat	ocean water	1	0
Pearl to Kukra road	road	1	9
Bluefields to Punta Aguila road	road	1	0
Bluefields to Punta Aguila rail	rail	1	52
Prinzapolka to Puerto Cabeza road	road	1	0
Tortuguero to Kukra road	road	2	0
Tortuguero to Pearl water option	inland water	2	0
Cruz de Rio Grande to Kukrahill road	road	2	63
Pearl to Bluefields barge	inland water	2	0
Pearl to Bluefields fishing boat	ocean water	2	0
Pearl to Kukra Road	road	2	0
Bluefields to Punta Aguila road	road	2	0
Bluefields to Punta Aguila rail	rail	2	0
Prinzapolka to Puerto Cabeza road	road	2	0
Tortuguero to Kukra road	road	3	0
Tortuguero to Pearl water option	inland water	3	0
Cruz de Rio Grande to Kukrahill road	road	3	63
Pearl to Bluefields barge	inland water	3	0
Pearl to Bluefields fishing boat	ocean water	3	0
Pearl to Kukra road	road	3	0
Bluefields to Punta Aguila road	road	3	0
Bluefields to Punta Aguila rail	rail	3	0
Prinzapolka to Puerto Cabeza road	road	3	0
Tortuguero to Kukra road	road	4	0
Tortuguero to Pearl water option	inland water	4	15
Cruz de Rio Grande to Kukrahill road	road	4	0
Pearl to Bluefields barge	inland water	4	0
Pearl to Bluefields fishing boat	ocean water	4	0
Pearl to Kukra road	road	4	0
Bluefields to Punta Aguila road	road	4	0
Bluefields to Punta Aguila rail	rail	4	10
Prinzapolka to Puerto Cabeza road	road	4	38
Tortuguero to Kukra road	road	5	0
Tortuguero to Pearl water option	inland water	5	0
Cruz de Rio Grande to Kukrahill road	road	5	0
Pearl to Bluefields barge	inland water	5	0
Pearl to Bluefields fishing boat	ocean water	5	0
Pearl to Kukra road	road	5	0
Bluefields to Punta Aguila road	road	5	0
Bluefields to Punta Aguila rail	rail	5	0
Prinzapolka to Puerto Cabeza road	road	5	63

4.3.3. Bluefields to Punta Aguila Rail-to-Road Transition with a Road-Construction Limit of 63 KM Per Year

There were several recommended transportation modes within the model. Should the Nicaragua canal come to fruition, a deep-water port would be constructed at Punta Aguila (HKND Group, 2014). This port would effectively serve not only as an ingress and egress point for the canal, but also as the region's access to global markets. Bluefields would be the regional manufacturing and value-added processing center for RAAN and RAAS products. From there, the finished products could be shipped to Punta Aguila where the port infrastructure would enable global supply chain integration. Using Latin-American rail and trucking rates per Ton-kilometer, rail was approximately one-quarter the cost per Ton-kilometer. Constructing the rail was roughly 30% more per kilometer than the roads. Through sensitivity analysis using the 63 kilometer of road construction per year constraint, it was determined that, for roads to replace railways, the shipping costs would have to more than quadruple from less than $0.05 per Ton-kilometer to $0.18 per on-kilometer.

In Latin America where rail shipments are much more expensive than in the United States, only one rail company met this threshold. As a result, it is very unlikely that the calculus would change given the rail-transportation cost advantage over trucking. However, if the cost per Ton-kilometer exceeded $0.18 via rail, road transportation would become the more cost-effective approach to move goods. This situation is unlikely because the rail infrastructure would be new and because it would cost much less to operate and maintain the railway and to move goods.

It is also important to note that, should rail expenses meet the threshold of $0.18 per Ton-kilometer, the cost to construct and operate the railway and to move goods across the network would drastically increase. The drastic adjustment is based on the premise that Bluefields is the central node and that all goods and products would travel from Bluefields to Punta Aguila; this estimate assumes that global markets would consume Nicaraguan beef, seafood, and manufactured products. The cost of the network triples when the new $0.18 cost per Ton-kilometer is introduced for rail when compared with the current Latin-American rates. If North-American rates are used, the cost to construct and operate the railway and to move goods across the network during the 50-year period almost quintuples to $4.7 billion!

Should a road be constructed in lieu of a railway from Bluefields to Punta Aguila, using the 63 kilometers of road construction per year constraint, the distribution of construction becomes very even. In fact, the road from Bluefields to Punta Aguila is suggested for the first year. In the following years, there is a distribution without any large differences. This difference is largely due to the 63-kilometer ceiling and the amount of road construction that must occur given the 5-year nature of the construction project. Should there be no construction of the Nicaragua canal, there will not likely be a deep-water port at Punta Aguila, and most products will be transported from Bluefields and Puerto Cabezas given their current role in the RAAN and RAAS economies as well as their port infrastructure. Table 16 reflects the introduction of the annual 63-kilometer construction constraint.

Table 16

Construction distribution if a road were constructed from Bluefields to Punta Aguila, as opposed to rail, using the 63-kilometer per year road-construction constraint

Arc	**Mode**	**Year**	**KM**
Tortuguero to Kukra road	road	1	0
Tortuguero to Pearl water option	inland water	1	0
Cruz de Rio Grande to Kukrahill road	road	1	0
Pearl to Bluefields barge	inland water	1	0
Pearl to Bluefields fishing boat	ocean water	1	0
Pearl to Kukra road	road	1	0
Bluefields to Punta Aguila road	road	1	61
Bluefields to Punta Aguila rail	rail	1	0
Prinzapolka to Puerto Cabeza road	road	1	0
Tortuguero to Kukra road	road	2	0
Tortuguero to Pearl water option	inland water	2	0
Cruz de Rio Grande to Kukrahill road	road	2	62
Pearl to Bluefields barge	inland water	2	0
Pearl to Bluefields fishing boat	ocean water	2	0
Pearl to Kukra road	road	2	0
Bluefields to Punta Aguila road	road	2	1
Bluefields to Punta Aguila rail	rail	2	0
Prinzapolka to Puerto Cabeza road	road	2	0
Tortuguero to Kukra road	road	3	0
Tortuguero to Pearl water option	inland water	3	15
Cruz de Rio Grande to Kukrahill road	road	3	48
Pearl to Bluefields barge	inland water	3	0
Pearl to Bluefields fishing boat	ocean water	3	0
Pearl to Kukra road	road	3	0
Bluefields to Punta Aguila road	road	3	0
Bluefields to Punta Aguila rail	rail	3	0
Prinzapolka to Puerto Cabeza road	road	3	0
Tortuguero to Kukra road	road	4	0
Tortuguero to Pearl water option	inland water	4	0
Cruz de Rio Grande to Kukrahill road	road	4	16
Pearl to Bluefields barge	inland water	4	0
Pearl to Bluefields fishing boat	ocean water	4	0
Pearl to Kukra road	road	4	0
Bluefields to Punta Aguila road	road	4	0
Bluefields to Punta Aguila rail	rail	4	0
Prinzapolka to Puerto Cabeza road	road	4	47
Tortuguero to Kukra road	road	5	0
Tortuguero to Pearl water option	inland water	5	0
Cruz de Rio Grande to Kukrahill road	road	5	0
Pearl to Bluefields barge	inland water	5	0
Pearl to Bluefields fishing boat	ocean water	5	0
Pearl to Kukra road	road	5	9
Bluefields to Punta Aguila road	road	5	0
Bluefields to Punta Aguila rail	rail	5	0
Prinzapolka to Puerto Cabeza road	road	5	54

4.3.4. Inland Waterway Use to Road Transition with a Road-Construction Limit of 100 KM Per Year

Like rail, there were alternative suggestions for road construction from the model. In the interior of the RAAS province, there were two suggested uses of inland waterways as opposed to roads based on cost: Pearl Lagoon to Bluefields and Tortuguero to Pearl Lagoon. Although the initial expenses to construct inland-waterway routes that are navigable are high, the cost per Ton-kilometer to move goods via waterway is, by far, the least expensive. At $4,000,000 per kilometer to construct, waterway construction costs approximately 5 times what road construction would cost. However, at $0.0114 per Ton-kilometer, moving goods was approximately 15 times cheaper than transportation with commercial trucks.

For it to become financially advantageous to build roads and to transport goods via truck, the model estimates that, over the 50-year period, river transportation costs per Ton-kilometer would have to increase 16-fold, equating to $0.175 per Ton-kilometer. This scenario is very unlikely given that the newly created inland-waterway transportation routes would inspire new or almost new vessels to accommodate the massive amounts of logs and beef that need to be moved to Bluefields. It is also important to note that the model reverted to the 100-km road-construction constraint per year versus 63 km per year to meet the 5-year requirement. With the lower road-construction constraint, it does not matter what it costs per on-kilometer to move via river; even at $10 per Ton-kilometer, using inland-water transportation, the model would not change because of the construction constraint.

One other interesting element was that the total network construction, operating expenses, and movement of goods cost roughly $1.645 billion over the 50-year period. This number also assumed Latin-American rates per Ton-kilometer for railways and roadways. It is very unlikely that waterway transportation would be replaced with roads given the savings and efficiencies realized using vessels via inland waterways.

It is also important to note the construction distribution of infrastructure adjustments once roads are used in lieu of the inland waterways. Even the high-side road-construction constraint of 100 kilometers per year forces a relatively even construction distribution after year one due to the network's increased road capacity. Table 17 reflects using roads versus waterway arcs throughout the network.

Table 17

Distribution of construction of arcs using road versus waterway arcs

Arc	**Mode**	**Year**	**KM**
Tortuguero to Kukra road	road	1	0
Tortuguero to Pearl water option	inland water	1	0
Cruz de Rio Grande to Kukrahill road	road	1	0
Pearl to Bluefields barge	inland water	1	0
Pearl to Bluefields fishing boat	ocean water	1	0
Pearl to Kukra road	road	1	0
Bluefields to Punta Aguila road	road	1	0
Bluefields to Punta Aguila rail	rail	1	0
Prinzapolka to Puerto Cabeza road	road	1	0
Tortuguero to Kukra road	road	2	41
Tortuguero to Pearl water option	inland water	2	0
Cruz de Rio Grande to Kukrahill road	road	2	0
Pearl to Bluefields barge	inland water	2	0
Pearl to Bluefields fishing boat	ocean water	2	0
Pearl to Kukra road	road	2	0
Bluefields to Punta Aguila road	road	2	0
Bluefields to Punta Aguila rail	rail	2	0
Prinzapolka to Puerto Cabeza road	road	2	0
Tortuguero to Kukra road	road	3	2
Tortuguero to Pearl water option	inland water	3	0
Cruz de Rio Grande to Kukrahill road	road	3	98
Pearl to Bluefields barge	inland water	3	0
Pearl to Bluefields fishing boat	ocean water	3	0
Pearl to Kukra road	road	3	0
Bluefields to Punta Aguila road	road	3	0
Bluefields to Punta Aguila rail	rail	3	0
Prinzapolka to Puerto Cabeza road	road	3	0
Tortuguero to Kukra road	road	4	0
Tortuguero to Pearl water option	inland water	4	0
Cruz de Rio Grande to Kukrahill road	road	4	28
Pearl to Bluefields barge	inland water	4	0
Pearl to Bluefields fishing boat	ocean water	4	0
Pearl to Kukra road	road	4	0
Bluefields to Punta Aguila road	road	4	0
Bluefields to Punta Aguila rail	rail	4	0
Prinzapolka to Puerto Cabeza road	road	4	72
Tortuguero to Kukra road	road	5	0
Tortuguero to Pearl water option	inland water	5	0
Cruz de Rio Grande to Kukrahill road	road	5	0
Pearl to Bluefields barge	inland water	5	0
Pearl to Bluefields fishing boat	ocean water	5	0
Pearl to Kukra road	road	5	9
Bluefields to Punta Aguila road	road	5	0
Bluefields to Punta Aguila rail	rail	5	62
Prinzapolka to Puerto Cabeza road	road	5	29

4.3.5. Road Construction to Fishing Boat or Inland Waterway with a Road-Construction Limit of 100 KM Per Year

There were four transportation modes considered for the network in the RAAN and RAAS provinces: roads, railways, and inland waterways along with fishing vessels using the Caribbean Sea. Given the potential to move more seafood to global markets for consumption, a transportation arc was considered for Pearl Lagoon to Bluefields. There were three options for this arc: a road to facilitate commercial truck transportation, an inland waterway to enable seafood transportation, and a fishing vessel from Pearl Lagoon to Bluefields via the Caribbean Sea. Unfortunately, it is estimated to cost $12.28 per ton-kilometer to move seafood from the Pearl Lagoon area to Bluefields via the Caribbean Sea. However, it is important to note that there is no major initial investment required to enable the movement of seafood via water, whereas the road costs approximately $846,000.

Three modes were considered in order to determine what would eventually transition the base-recommended network away from roads. Using the high-side constraint of 100 km per year of construction, the threshold to transition mode was $0.014 per Ton-kilometer; this threshold was very interesting because, in this scenario, the inland waterway becomes the primary source of transportation. Given the inexpensive cost to move goods via inland waterways, transportation with a fishing vessel is not a viable or cost-effective option. Considering that it costs $12.28 per Ton-kilometer to move seafood via the Caribbean Sea to Bluefields, even if the cost to move goods decreased 100-fold, which is unlikely, the inland waterway remains the selected mode. At $0.014 per Ton-kilometer, the cost to construct and operate the inland waterway and to move goods across the network is $1.533 billion. The overall cost of the network does not experience much change due to the inland-water option where the cost per Ton-kilometer is the least expensive of all modes.

Given the 100 kilometers of road-construction constraint, the five-year construction schedule reflects a very similar pattern to the baseline results with Latin-American rates for commercial truck transportation and for trains. The only major difference is the inland-waterway construction from Pearl Lagoon to Bluefields during year three of the network construction. Table 18 shows the construction schedule using inland waterway from Pearl Lagoon to Bluefields.

Table 18

Distribution of transportation-mode construction with an inland waterway from Pearl Lagoon to Bluefields

Arc	Mode	Year	KM
Tortuguero to Kukra road	Road	1	0
Tortuguero to Pearl water option	inland water	1	0
Pearl to Bluefields barge	inland water	1	0
Pearl to Bluefields fishing boat	ocean water	1	0
Pearl to Kukra road	Road	1	0
Bluefields to Punta Aguila road	Road	1	0
Bluefields to Punta Aguila rail	Rail	1	0
Prinzapolka to Puerto Cabeza road	Road	1	0
Tortuguero to Kukra road	Road	2	0
Tortuguero to Pearl water option	inland water	2	0
Cruz de Rio Grande to Kukrahill road	Road	2	28
Pearl to Bluefields barge	inland water	2	0
Pearl to Bluefields fishing boat	ocean water	2	24
Pearl to Kukra road	Road	2	0
Bluefields to Punta Aguila road	Road	2	0
Bluefields to Punta Aguila rail	Rail	2	0
Prinzapolka to Puerto Cabeza road	Road	2	0
Tortuguero to Kukra road	Road	3	0
Tortuguero to Pearl water option	inland water	3	15
Cruz de Rio Grande to Kukrahill road	Road	3	61
Pearl to Bluefields barge	inland water	3	24
Pearl to Bluefields fishing boat	ocean water	3	0
Pearl to Kukra road	Road	3	0
Bluefields to Punta Aguila road	Road	3	0
Prinzapolka to Puerto Cabeza road	Road	3	0
Tortuguero to Kukra road	Road	4	0
Tortuguero to Pearl water option	inland water	4	0
Cruz de Rio Grande to Kukrahill road	Road	4	37
Pearl to Bluefields barge	inland water	4	0
Pearl to Bluefields fishing boat	ocean water	4	0
Pearl to Kukra road	Road	4	0
Bluefields to Punta Aguila road	Road	4	0
Bluefields to Punta Aguila rail	Rail	4	0
Tortuguero to Kukra road	Road	5	0
Tortuguero to Pearl water option	inland water	5	0
Cruz de Rio Grande to Kukrahill road	Road	5	0
Pearl to Bluefields barge	inland water	5	0
Pearl to Bluefields fishing boat	ocean water	5	0
Pearl to Kukra road	Road	5	0
Bluefields to Punta Aguila road	Road	5	0
Bluefields to Punta Aguila rail	Rail	5	62
Prinzapolka to Puerto Cabeza road	Road	5	38

4.3.6 Relaxing the 5-Year Construction Requirement to 10 Years

Transportation construction in Central America has a propensity to be slow due to resource and labor constraints. Although it is possible to construct and deploy a 400 plus mile multimodal transportation network in five years, it is more probable that it would take longer to become fully functional. As such, it was important to test a 10-year construction period to determine cost as well as viability. When relaxed to a 10-year period, using Latin American rates at $0.17 per Ton-km for trucking and $0.0462 per Ton-km for rail, the network cost declined to $1,162,306,558 with the initial public infrastructure investment costing $455,997,512 and private sector operations and maintenance costing $706,309,046 over 50-years. Unsurprisingly, the network wasn't fully connected until year 10; the cost savings when compared to the same inputs over a 5-year period were achieved as cost to move goods and services were postponed until year 10. Although it appears to result in savings, lost economic activity over the five-year period may account for a significant loss to the RAAN and RAAS. In addition, modes suggested by the solution for each arc went unchanged in the 10-year constraint indicating the same road, inland waterway and rail results.

4.4. Discussion

The focus for the main research questions pertained to the minimum cost of developing a regional transportation network, including the recommended modes of transportation, in order to realize optimal economic and societal potential; the long-term transportation requirements to ensure achievement of the maximum benefit; contributions to the global economy due to growth and supply chain integration and municipal (*cabildo*) level growth potential as a result of new transportation options. Each result is articulated below to ensure that the end user, Nicaragua, is prepared to develop, to engineer, to construct, and to deploy the multimodal network should financing or an economic impetus come to fruition.

4.4.1. Minimum Cost to Develop a Multimodal Transportation Network in the RAAS and RAAN Provinces

The results for the first question pertaining to the minimum cost of development as well as the attributes associated with the network are described in the following sections. A variety of scenarios were analyzed for minimum costs. This section will begin with the lowest cost option with assumptions using North American rates and transition into more realistic scenarios using Latin American rates for rail and road transportation costs.

4.4.1.1. The Minimum Cost Option

The minimum-cost option for developing and deploying the multimodal network was $861,419,624.87. In the developed world, this scenario would be likely; however, Nicaragua is the second-most impoverished nation in the Western Hemisphere, following Haiti. As a result, it is unlikely that the network will cost $861 million over a 50-year period. The infrastructure will be new, but the assets used to move goods will be older and will fall into the pattern of other Central-American states due to the lack of available resources utilized by small and medium-sized firms. It is also improbable that the central government will implement a proper operation-and-maintenance schedule during the 50-year period, resulting in higher costs. Given this paradigm, the costs of moving goods via truck at $0.17 per Ton-kilometer and $0.0462 for rail are more likely than the North American rates The first 5-10 years should reflect a less-expensive scenario, resulting in somewhere between $1.4 and $1.5 billion to construct and maintain the network and to move goods throughout the network over a 50-year period.

It is anticipated that, somewhere between years 5 and 7 post construction, the roads will require their first major maintenance. Most 10-ton roads constructed using hot-mixed asphalt have a lifecycle of 10 years prior to resurfacing (Schlegel, T., Puiatti, D., Ritter, H. J., Lesueur, D., Denayer, C., & Shtiza, A., 2016). In Nicaragua, it is anticipated that the roads will deteriorate more quickly due to the inability to properly enforce weight and safety standards. It is probable that insufficient operation-and-maintenance funding will be available around years 5 or 7 post construction; as a result, network deterioration will cause higher maintenance expenses and lower fuel efficiency for trucks. A combination of low maintenance budgets and higher transportation expenses will place the trucking cost per Ton-kilometer closer to the Latin-American average; therefore, the estimate for 50-year operations will likely fall between $1.4 and $1.5 billion.

4.4.1.2. When Would Infrastructure Recommendations Change?

It was important to examine what potential triggers would result from constructing roads versus railways between Bluefields and Punta Aguila. All model iterations using North-American and Latin-American rates indicated that constructing, maintaining, and operating a railway would be more cost effective than a road. This result was due to similar construction costs for both infrastructure modes as well as transportation expenses per Ton-kilometer where rail transportation costs approximately 25% that of trucking. The route would be fixed because Punta Aguila was the only logical deep-water port-construction site due to the potential for canal construction should Chinese investment occur.

For the rail option to transition to a road, the cost to move good across the network would have to be $0.18 per Ton-kilometer. Unfortunately, this situation would then create a network cost of $4.73 billion. Outside this scenario, there are other triggers which would lead to revisiting the decision to construct and use a railway versus roads. First, the energy market. It is possible that new technologies could lead to more efficient use of oil; if this case happened, global supply and demand imbalances could occur, leading to drastically lower energy expenses. Second, if a network were constructed, government efficiencies as well as information-technology investments could occur. This scenario would have a major influence on trucking expenses because back-haul solutions and fewer institutional roadblocks would be identified. The prices to transport goods across the region would drastically decline if the region's operational model reflected the one in the United States; this is precisely why rates are so much lower per Ton-kilometer in the United States even though labor has a higher cost. Should energy costs decline because of technological improvements or major supply injections as well as discoveries and implementation of efficiencies, it would be prudent to revisit the model; however, it is unlikely that either of the two potential triggers will occur within the next decade or two given the region's fiscal and governance realities as well as the economics and geopolitics of oil.

It was important to examine what potential triggers would result in constructing a road versus a waterway between El Tortugero to Kukrahill via Camp II Road. The qualitative requirement to revisit this mode and to transition to a road would entail a 16-fold increase in the river transportation cost to $0.175 per Ton-kilometer. Given both North-American and Latin-American rates for transportation, all modeled scenarios pointed to a waterway being the most cost-effective solution over 50 years. This finding was very interesting given that it cost 5 times as much to prepare 1 kilometer of waterway for transportation versus constructing 1 kilometer of road. In addition, it costs approximately 40 times as much to maintain each kilometer of waterway versus road if the route is used for major transportation requirements.

Costs to ship goods via roads, however, are roughly 10 times greater than by waterway if using the North-American expense standard and 16 times greater if rates from Latin America are utilized. As such, over the 50-year period, enough cost savings are accrued using waterway transportation to offset the higher construction and maintenance costs unless there is a 16-fold increase for shipping rates using this mode. Given that the Nicaraguan government would struggle to pay for maintenance, a pay-for-service or cooperative model is likely. These pay-for-service models are quite common in the region, especially when toll roads are examined. Should the government experience difficulty with developing and deploying a viable user fee or finding a company willing to partner with it, there is a greater likelihood than not that maintenance would suffer and be deferred, resulting in much higher transportation costs due to network inefficiencies. A public-private partnership or effective user fee would ensure that the government has the resources necessary to maintain the network. Should neither of the two scenarios come to fruition, a road may be the better option because the costs would change.

Like the rail example, energy costs as well as inefficiencies and older-vehicle use result in higher-than-North-American costs for truck transport. Although North-American trucking rates still preferred a waterway over road construction and use, new technology advances as well as more effective governance may result in a cost that forces a re-examination of utilizing a waterway versus road construction. Overall, two major catalysts would be required to trigger reconsideration for the selected modes given the volume of data used to determine the minimum-cost network beyond the threshold determined with the sensitivity analysis.

It was important to examine what potential triggers would result in using the Caribbean Sea to transport seafood rather than constructing a road from Pearl Lagoon to Bluefields. In essence, it costs approximately 120 times as much per Ton-kilometer to transport seafood from

Pearl Lagoon to Bluefields using the fishing boats rather than a road. This is based on transport costs which do not account for refrigeration or ice using either mode. To utilize a fishing boat, the sensitivity analysis put this requirement at a 90-fold reduction in transportation pricing from over $12.00 per Ton-kilometer to $0.014 per Ton-kilometer. Even when Latin-American rates are considered, the cost is still 70 times more expensive. Given how product is moved in the region, there was no infrastructure requirement at Pearl Lagoon. Over 50 years, however, this cost difference is high enough to force road construction in order to achieve the same transportation capacity using the road versus the sea.

The efficiencies required to drive down costs in order to move goods via roads, especially technology, would likely be extended to fishing vessels, too. In the aggregate, given these cost savings, there are few scenarios which could change what the model demonstrated short of not having funds to construct and to maintain the road from Pearl Lagoon to Bluefields.

4.5. Long-Term Economic Empowerment

To realize their full economic potential, the RAAN and RAAS provinces must have a modern transportation network in place to ensure the smooth and unobstructed movement of goods throughout the region. The model focused on likely economic-development prospects based on the types of livestock and natural resources which could be used to propel the region's growth. In addition, a conservative approach to manufacturing and value-added-agriculture processing was created in the Bluefields region. This estimate assumes that transportation movement would create a free-trade zone as well as new economic opportunities. Should the canal come to fruition, there may be additional infrastructure requirements in and around Bluefields.

Industries such as tourism, crop and livestock production, seafood harvesting, mining, light manufacturing, and trade will benefit immensely should the multimodal transportation network be constructed. Operations and maintenance would be required to ensure that the continued movement of timber, beef, and other products achieves the growth targets. This long-term production and export picture, highlighted throughout the research, would be achieved over 50 years with the suggested model.

4.6. Global-Market and Supply Chain Integration

Construction of the multimodal network does not guarantee economic growth and development; however, global-demand forecasts for commodities which are currently produced in RAAN and RAAS provinces provide a positive opportunity. Presently, the RAAN and RAAS provinces have minimal transportation-and-logistics capacity to integrate into domestic or international markets. This capacity disadvantage is a direct result of the high transportation costs; put simply, it would cost too much to supply the consumption demand both in Nicaragua (outside of the region) and neighboring nations. To understand potential, it is important to analyze the global demand projections for beef, seafood, timber, textiles, and cocoa. These products are already driving micro and regional economies, and will determine the potential associated with economic growth in the region through supply chain contributions.

4.6.1. Beef

Among the largest opportunities for economic growth and development in the RAAN and RAAS provinces is beef production. Eastern Nicaragua has a strong tradition and history of ranching as well as land that is well suited for cattle grazing. Therefore, it is likely that producers will focus on beef production given the supply potential as well as price projections. According to the Food and Agricultural Organization of the United Nations (2017b), global prices for beef will decline slightly each year until 2024 when there will likely be a price increase. The network assumes a five-year build and subsequent connection to export facilities in Bluefields; given this match for increased prices simultaneous to transportation investments, local producers will likely expand the existing capacity in accordance with the estimates throughout this research. In addition, according to the OECD (2018), global demand for beef is also set to increase. Given the ranching culture, the opportunity to grow, and the efficient use of a new transportation network, Nicaraguan ranchers and value-added production facilities have an opportunity to enhance their operations. The domestic supply can access markets less expensively, and international consumers will also enjoy a less-expensive product.

4.6.2. Seafood

Like beef, seafood also has steady growth potential. On the Caribbean coast, aquaculture is robust; this research suggests significant growth for this sector in the last decade. According to the FAO (2018), various species are experiencing a tightening supply; combined with a positive global economic outlook for the next several years, prices are expected to increase. The rising tide for higher-priced seafood may float all proverbial boats in this instance. Additionally, seafood consumption in developed and middle-income countries continues to increase (FAO, 2018). Should investment for food-safety standards improve in Nicaragua, one could anticipate even greater demand and price premiums for local products. There is growth potential in this sector.

4.6.3. Timber

The potential for timber exports is among Nicaragua's greatest economic-development opportunities. If a viable transportation network is in place, the projected deforestation of 25-50%, depending on the *municipio*, is very likely based on historic examples in the region, such as the Brazilian Amazon and the Haitian countryside. Nicaraguan land owners would see both the initial return for the timber that was sold as well as the ability to raise cattle in areas that were once thick with forests. To most people in the RAAN and RAAS provinces, this chance may be the only growth opportunity given the rural nature of the region as well as the lack of economic modernization. Regional employment (outside the Caribbean coast) is predicated on the ranching culture. As such, job creation on small and large ranches would entice local support for growth in this area.

It is also important to note that the demand for timber will continue to increase through 2030 (FAO, 2018). The higher demand for Nicaraguan timber will be based on several factors: a projected skyrocketing world population, resulting in more needs for paper and hard woods; global GDP growth and lifting billions from poverty; environmental policies in developed countries that restrict deforestation; and improved hygiene practices for hundreds of millions of people, e.g., the use of toilet paper. The FAO (2018) report also highlighted the drastically increasing global demand for tropical woods as well as the need to implement environmental practices which encourage sustainable production.

Unfortunately, Nicaragua may encounter difficulty maintaining a sustainable timber industry. With a projected 25-50% rate of deforestation, the extremely impoverished nation will experience unintended consequences and societal costs. The transportation network may require additional operation-and-maintenance investments should runoff increase in areas; major storms, such as hurricanes, may cause more damage for forests to absorb high wind speeds and precipitation amounts. Also, if the government is unable to enforce truck weights, log transportation would further deteriorate road conditions. As such, environmental costs coupled with road deterioration may reduce the economic benefit associated with the network.

4.6.4. Textiles

Bluefields has the potential to enjoy tremendous growth and modernization should a free-trade zone be established and constructed in the region. Given the high unemployment rates, there is a large labor force available to fill positions which require semi-skilled and unskilled labor. Nicaragua could draw on nations such as Haiti and Egypt to determine what a scalable solution would entail given Central-American access to raw goods and materials which could feed a growing textile demand. According to Grandview Research (2017), the global textile market will grow to almost $1.4 trillion. The trade zone would depend on the ability to not only transport raw goods internally to the zone, but also to find a method to transport finished material for export. The Nicaragua canal would help the free-trade zone achieve optimal growth; however, without canal construction, opportunities may be limited based on the inability to move goods inexpensively via maritime transport channels. As such, the manufacturing sector, to include textiles, would unlikely come to fruition without major investment in the canal, a catalyst for regional growth and development.

4.6.5. Cocoa

Cocoa has enjoyed 2.1% growth per year and is anticipated to grow by 5.2% before 2020 (Cacaooro Nicaragua, 2018). Growth is attributed to a larger, emerging global middle class as well as new luxury confection markets in nations such as China, Russia, and Brazil (Cacaooro Nicaragua, 2018). The RAAN region, which would likely grow because of new demand, would be well positioned to meet the global demand. With a new transportation network in place, both raw goods and value-added production could occur at facilities in the region. Cacao accounts for a minimal effect on the transportation network, given the limited growth areas in RAAN provinces caused by climate, soil type, and elevation; however, this region would enjoy tremendous growth opportunities in the event that a network was constructed.

4.7. Other Major Factors to Consider

4.7.1. Changes in Commodity Prices Could Affect the Network

As Nicaraguan transportation planners develop a plan to execute the proposed multimodal network, it will be critical to locate long-term funding sources in order to sustain maintenance operations. There are various public-private partnership options which could leverage tolls to ensure that enough money is collected for long-term maintenance viability. Nicaraguan commodity production and value-added processing will flourish if there is access to international markets. As a result, a toll road is a major possibility given the traffic associated with new transportation-and-logistics options. Should commodity prices decrease or if there is a furtherance of global trade conflict, e.g., tariffs, it may be difficult for producers to compete with developed countries. As such, there could be a major decline in network use, leading to fewer collections for long-term maintenance. The central government will be unable to afford maintenance for this network, resulting in premature network deterioration.

Higher commodity prices would have the opposite effect although the system would be used more heavily. As a result, extra collections due to higher usage would likely cover the new maintenance requirements. One could anticipate cyclical changes during a 50-year period; hopefully, a feasible equilibrium is achieved for the price framework, resulting in adequate network maintenance.

4.7.2. Environmental and Social Costs

Unfortunately, societal consequences as a result of large transportation investments are not always positive. The model for Nicaraguan economic growth would likely cause some spillover effects in the short-term as experienced in Brazil. For example, in the Amazon region of Brazil, cattle ranching, likely to be the largest economic sector in RAAN and RAAS, led to significant deforestation (Jusys, 2016). In addition, road infrastructure would exacerbate the negative spillover impact as other industries are likely to develop as a result. In addition, in Brazil's Amazon region, two-thirds of the environmental destruction occurred with 50 kilometers of the transportation network (Mertens et al, 2002). In Nicaragua, new highways, rail or inland waterway infrastructure would impact the entire RAAN and RAAS likely manifesting a similar result.

Beyond environmental degradation, the coastal way of life may also experience change. New roads will lead to traffic congestion that could result in air pollution in *cabildos*; idling vehicles will also cause noise pollution. New societal challenges have the potential to negatively impact society resulting in increased medical cost and an adjustment to quality of life. Since 2014, several environmental impact assessments have been conducted in the RAAS; these studies can be leveraged to ensure minimal exposure to negative spillover effects. For example, water and air quality as a result of a future canal were assessed providing transportation planners with a template to avoid degrading policies (HKND Group, 2016). These studies examined the minutia associated with ecosystems, wildlife, water, the soil in the coastal region and offered remediation steps should infrastructural investments occur.

CHAPTER 5. CONCLUSIONS AND OBSERVATIONS

Eastern Nicaragua has few economic-development prospects without a modern transportation network. There is very little paved-road infrastructure in eastern Nicaragua, reducing the ability for both autonomous regions to prosper. There are a couple highways that lead into the capital from the northern Caribbean coast as well as one paved road under construction; in addition, there are limited inland water-transportation activities and some commerce at sea. The transportation situation inhibits broader logistics opportunities, subsequently limiting the global supply chain exposure for industries such as logging, ranching, manufacturing, and aquaculture. Although very unlikely, the prospect of a Nicaragua canal project would expedite transportation-infrastructure investments as well as regional modernization. Without the canal, the federal government may find it difficult to invest more than $1 billion into a multimodal network that enables economic transformation, logistic-network modernization, and global supply chain integration.

To reduce poverty and offer opportunity, this study sough to determine the lowest-cost transportation network that will enable the growth and development of a regional supply chain for local economic drivers. The model priced road, rail, and inland-waterway construction along with costs to move goods throughout the region as well as existing expenses to move seafood using a Caribbean route. The network focused on underserved areas that did not have access to roads while including the existing economic activity as a baseline business case to justify the expansion of logging, livestock, and agricultural activities as well as light manufacturing. The population center and critical network node was Bluefields because it is the capital and a regional trading center for the South Caribbean Autonomous Region.

In the network, freight was moved from *cabildo*s to Bluefields using the transportation volume prescribed by economic assumptions. Products throughout the network moved from within 25 kilometers of the municipal center and ended their journey at Bluefields where value-added activities occurred prior to moving to a proposed deep-water port at Punta Aguila. The multimodal transportation-network design model includes Bluefields as the critical node based on canal-construction plans, existing infrastructure, and forecast transportation patterns. Mode flexibility was the basis for this research in order to ensure the most-inexpensive and efficient model for Nicaraguan transportation planners.

5.1. Study Results

Overall, the research yielded three modes for the network: roads for several arcs, inland waterways, and rail. Based on the model, the least-costly solution was a multimodal network that took approximately 5 years to construct. The total cost for a 50-year period, including the initial construction expenses, operations, and maintenance as well as the cost to move goods across the network, came to $861,419,624.87. It is important to note that, fiscally, it would be difficult to budget for this funding level, and from a practical standpoint, it is unlikely that the region would have enough equipment and skilled workers to meet the 5-year construction requirement. To achieve the 5-year construction requirement at $816,419,624.87, all conditions had to be optimal to include the costs to move goods associated with North-American rates. Given Latin-American inefficiencies and aged equipment, the cost to move goods was likely much higher. In order to gauge what a network would cost to construct, to manage, and to operate as well as to move goods throughout that network over a 50-year period using a trucking rate which was consistent with the cost per Ton-kilometer in Nicaragua as well as an average of Latin-American railways, it was determined that the estimated cost for this network would be $1,533,668,869.68. The new price represented almost a $700 million higher cost; however, the cost reflected the regional reality with respect to each Ton-kilometer.

From a mode perspective, roads were the primary mode selected by the linear program. There was an internal waterway from inland communities that would be improved to move goods to Bluefields, and rail was selected to transport goods from Bluefields to the deep-water port at Punta Aguila. These modes were selected given the much lower costs to move goods versus the high trucking expenses.

5.2. Quality and Robust Results

Overall, the results were highly robust. The model selected modes that held quite well when the sensitivity analysis was performed. For example, to adjust mode-construction suggestions, some costs had to decrease almost 100-fold before the model transitioned to an alternate scenario. As such, minor cost adjustments for the infrastructure or moving goods across the network were not meaningful enough to adjust the suggested construction design for the Solver run. This pattern held for road to rail, road to inland waterway, and road to sea transportation. The parameter changes had to be very high to adjust the suggested build.

Some constraints were not included in the model. For example, skilled-labor shortages based on low education attainment were not included because data were difficult to locate. Population shifts were not taken into account either, but one could assume that new economic opportunities would potentially lead to an inflow of residents seeking to improve their quality of life. The model also made the assumption that global demand would likely absorb all Nicaraguan exports from the region, including beef, timber, seafood, and finished manufactured goods. Additional trade integration would likely lead to import requirements which offer a great opportunity for further research about how backhaul could influence the cost to move goods throughout the region. Another potential constraint was the economic isolation caused by geopolitical challenges which are currently affecting the Ortega government.

5.3. Status of the Nicaragua Canal

In 2016 when this research project began, HKND Group and the Nicaraguan government were projecting a high likelihood that the canal-construction project would come to fruition. Throughout the research period, however, the status changed remarkably as setback after setback resulted in a decreasing probability that the canal-construction project would occur. Although in February 2019 the project is still reported as proceeding, the requisite infrastructure investments have yet to occur, and political and economic instability grips both Nicaragua and one of its main allies, Venezuela. In addition, it appears that the Chinese government has lost its appetite to invest in the project because the Panama Canal appears to meet global, maritime supertanker requirements. Given the economic challenges in China, improving relations between Panama and China, and the internal strife in both Nicaragua and Venezuela, it appears that the canal is not likely to be constructed.

Should no canal come to fruition, a deep-water port at Punta Aguila will be unlikely because Bluefields or Puerto Cabeza would increase shipping capacity should new transportation infrastructure be constructed. With the RAAN and RAAS network, improvements for the Bluefields port infrastructure would have to occur in order to enable timber, beef, seafood, and other products to meet their global consumer demand. This transition would also result in a less-expensive transportation network given the removal of the arc from Bluefields to Punta Aguila.

5.4. Exogenous Factors Could Influence Whether The Network Is Constructed

There are several externalities which will influence whether the network is constructed. Chief among the factors would be the construction of a Nicaragua canal. Given the cost as well as nearby options, it is very unlikely that this project will come to fruition. The Panama Canal to the south offers sufficient maritime transportation capacity, so a canal slightly north would not likely meet a new global demand requirement. In addition, the Panama Canal Authority hosts one of the largest free-trade zones in the world, encouraging continued investment in the canal and its associated infrastructure.

HKND Group (2014) believed otherwise when it invested in the design and engineering work and continues to work with the Nicaraguan government to determine feasibility. At a $50-100 billion cost, there are few models which suggest that, one, the canal is needed; and, two, the canal will not likely rival the Panama Canal. It is important to note that, during the planning stages for the Nicaragua project, the Venezuelan government was involved with investments ranging from refineries to support energy demand and roads. The political and economic situations have changed in Venezuela, resulting in the inability to contribute to infrastructure. Should something change, however, e.g., the demand for a new canal to accommodate a new class of supertankers, it is possible that the catalyst would lead to canal construction A project of this magnitude would require roads in the proposed network in order to meet material-delivery requirements.

Financing could also be difficult for Nicaragua. The Atlantic-Interconnectivity project financed by the Inter-American Development Bank (IBD) contained stringent deliverables as well as repayment requirements. At about 6% of the total network cost, assuming the lowest estimate, the IDB may decide that the network’s road component is not scalable. The smaller project could be due to a lack of maintenance or difficulty servicing the loan. Without a major catalyst, e.g., the canal, the IDB and other financial institutions may be reluctant to fund the project. The central government could issue bonds, but at 7% GDP, it may be difficult to raise the money.

A global recession or depression could also result in changing public-sector priorities. Should this event occur, it is very likely that funds which were earmarked to maintain the existing roads would be reprogrammed into social programs in order to ensure that basic living standards are met. Already the second-most impoverished nation in Latin America, Nicaragua would likely have to shift funds to programs which deal with health or food distribution. There are other factors which could influence the network's construction; however, the canal's construction, project financing, and global economic conditions will most likely influence whether this network is constructed and maintained.

5.5. Reducing the Logistics "Tax" Placed on Small Transport Companies

Currently, there is a logistics "tax" which is levied on small transportation firms that transport goods throughout Nicaragua. Larger companies have access to newer fleets and have the resources to more effectively maintain their respective vehicles. In addition, larger firms tend to deal with companies near modern infrastructure, e.g., ranches that have export requirements and are located near paved roads. These firms use systems which may offer backhaul opportunities because their destination may have a local branch that can solicit business from different regions within the country. In the aggregate, small firms and farms are subject to higher transportation costs because of older assets, no system integration at the destination, and poorly maintained and unpaved roads.

If the network comes to fruition, money will flow to the region. Investments beyond transportation infrastructure will be made, encouraging private-sector capital and deal flow. Smaller firms may have the opportunity to leverage the economic progress and to purchase newer vehicles. Paved roads, coupled with more sophisticated systems in place, e.g., Information Technology investments for the free-trade zone located in Bluefields, may offset some of the logistics "tax" which is currently plaguing smaller firms. Overall, the network may not entirely mitigate the difference for what smaller and larger companies pay per Ton-kilometer, but it will offset some of the gains currently enjoyed by larger companies.

5.6. Contribution to Literature

Pribadi et al. (2015) in their work took 40 years of evolving and improving transportation network designs and applied them to economic-development disparities in Indonesia. In Southeast Asia, transportation investments primarily benefited large population areas resulting in parallel development challenges found throughout this research; for example, there were many raw materials, an available workforce and an opportunity for tremendous value-added economic activity but no way to move supply into global markets.

This research will contribute to the body of knowledge through expanding upon Pribadi et al.'s research through the introduction of a Latin American node and arc model using over 40 years of modern transportation network design theories. This research also demonstrates the potential associated with logistic network modernization as a direct result of transportation investments and provides unique insight into various product integration potential into global markets for beef, textiles, seafood, timber and other products.

5.7. Further Research

This study provides useful research for Nicaraguan transportation planners and economic developers. However, there are a number of areas that would benefit from additional research given the region's economic growth potential and the potential to realize many public benefits if the area is developed. Further research should include, but not be limited to,

1. Further investigation about the complete economic-development and growth potential using primary and secondary impact analysis. This investigative work will drive decisions about what type of infrastructure would best meet the municipal-level transportation and development requirement.
2. Further refinement of network costs using a more-extensive analysis and sensitivity for operations and maintenance based on global price shocks, inflation, etc. Energy and construction materials should be the focus areas because they are the largest expenses within the network and for transportation movements that occur during the 50-year period.
3. Municipal-level community development as transportation and economic-development opportunities come online. Each municipality will enjoy unique growth due to the different sectors which will benefit, resulting in local improvements.
4. Further refinement of global supply chain integration through additional efficiency discovery in beef, timber, and seafood markets. Sensitivity analysis could occur based on global supply imbalances, e.g., losses in aquaculture due to overfishing or climate change, or a reduction in beef consumption due to air pollution.
5. Perform a feasibility study for constructing a deep-water port at Bluefields if no canal is built. Economic-development and growth prospects are immense given the transformation that would occur if a transportation network comes to fruition; therefore, this exploration may determine the economic growth potential without the canal.
6. Design a free-trade zone at Bluefields in order to determine manufacturing capacity as well as how this zone could affect value-added growth in sectors such as timber and

agriculture. Also, researchers should examine the workforce in order to determine what industry types could come to Nicaragua to convert raw material into exportable products.

7. The positive and negative implications of growth should be studied further to ensure that Nicaraguan society is well prepared for economic development. In addition, there should be a heavy emphasis on policy development to ensure that negative environmental spillover effects such as air and water quality are preserved while growing the economy. Sustainable economic and environmental practices should also be researched further to ensure that Nicaragua responsibly achieves development avoiding the environmental impact of Haiti.

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