1-1-2022

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Recommended Citation

Aspila, Christopher, "Modelling Cross-Border Rail Intermodality in the Windsor-Essex Context" (2022). *Electronic Theses and Dissertations*. 8710.
https://scholar.uwindsor.ca/etd/8710

Modelling Cross-Border Rail Intermodality in the Windsor-Essex Context

By

Christopher Aspila

A Dissertation
Submitted to the Faculty of Graduate Studies
through the Department of Civil and Environmental Engineering
in Partial Fulfilment of the Requirements for
the Degree of Doctor of Philosophy
at the University of Windsor

Windsor, Ontario, Canada

2021

Modelling Cross-Border Rail Intermodality in the Windsor-Essex Context

by

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ABSTRACT

Shipment by truck dominates the cross-border flow of commodities in both directions between Canada and the United States (Anderson and Coates, 2010; Anderson, 2012; Anderson and Brown, 2012; and Aspila and Maoh, 2014). An individual truck typically pulling one or two trailers is an inefficient way to move goods over long distances (Eom et al., 2012) when freight trains with three or more 4400 horsepower diesel-electric locomotives pull over two-hundred intermodal containers loaded on rail cars throughout North America every day.

Windsor, Ontario is an example of a border community in Canada and hosts the busiest border crossing between Canada and the United States. Crossings include two road, one rail and a sea port of entry (United States Department of Transportation – Bureau of Transportation Statistics, 2017). Presently the majority of cross-border import and export traffic is by road haulage. In addition to serving as a port of entry for goods being imported or exported between the two countries there is also a substantial local manufacturing base that consumes and produces goods on both sides of the border.

There are several existing railroad border crossings including a rail tunnel between Windsor, Ontario and Detroit, Michigan. There must be a rational reason why commodities are shipped across the border using trucks and not rail. This dissertation research is proposed to answer the question of is rail viable for shipping commodities cross-border or as part of the cross-border supply chains? A network optimization model of Canada-US rail freight is developed to address this question. The model is first used to assess whether location of a conventional, large-scale intermodal facility in Windsor is viable. Results indicate that it is not. It is then applied to a scenario where innovative small-scale intermodal transfer facilities are located in Windsor and at other significant rail nodes in Ontario. Results indicate that this is a more viable strategy for increasing the rail share of cross-border freight movement.

ACKNOWLEDGEMENTS

Writing a dissertation in an ongoing global COVID-19 pandemic has been a second full-time job on top of my regular full-time job as a Senior Urban Planner for a mid-sized city and being a husband and parent of two elementary school aged children and remotely caring for two aging parents. I would like to thank my wife Melissa for her patience and support throughout this journey and my daughter Sophia and son Mattias for trying to behave while Dad finished his homework for “Grade 29”.

I would like to thank my parents, Keijo and Hilary Aspila for their continuing support as I continue my journey through life-long learning, my dad Keijo Aspila and my uncle Dr. Gary Kaiura for their continued inspiration about graduate studies and research.

My Co-Advisors Dr. William P. Anderson and Dr. Hanna Maoh deserve a huge thank you. When I started this journey I was about 10-15 years older than the typical PhD Student. I think that I may have been their first or one of their first graduate students with an established career and family. The things I have learned during this research project have repeatedly taught me that there is more to learn. Each time I’ve answered a question the answer has led to additional questions to be answered. I’m grateful for having the opportunity to learn from Bill’s expertise about the Canada-US border, transportation systems, economics and politics, and Hanna’s expertise with transportation systems, GIS and technical brilliance.

Additionally, I would like to thank the following members of the team at the Cross-Border Institute for their assistance and support as part of this research: Dr. Chris Lee, Dr. Shakil Khan, Pat, Eva and Terence.

I would like to thank Dr. Jacek Malczewski of the Geography Department at the University of Western Ontario for instilling confidence, inspiring me and empowering me throughout my Master’s research which was the starting point of my post-graduate journey.

I would like to thank Thom Hunt, the City Planner at the City of Windsor for his involvement in setting up the original meeting with staff and the two researchers who by chance would eventually become my PhD Co-Advisors.

Lastly, I would like to thank my Examination Committee comprised of Dr. Clarence Woudsma from the University of Waterloo who served as my External Examiner, Dr. Guoqing Zhang, Mr. John Tofflemire, Dr. Chris Lee, Dr. William P. Anderson and Dr. Hanna Maoh of the University of Windsor.

Now that this research is complete, I hope that the knowledge and experienced gained serves Windsor-Essex, firms, municipalities and the academic community well in how to make use of opportunities with rail intermodal.

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INTRODUCTION

1.1 Preface

This dissertation is about whether it makes sense to locate an intermodal terminal for cross-border container traffic in Windsor-Essex, whether it be a full-scale intermodal terminal or a small-scale facility that makes use of a small-scale intermodal technology. In the case of small-scale facilities the research explores whether these should be located in Windsor and other Ontario cities. The research includes an overview of the North American rail network, development of a model that can be applied to cross-border rail commodity flows, an examination of developing a full-scale intermodal terminal in Windsor-Essex, and an examination of deploying small-scale intermodal technology to deliver intermodal services in Windsor Essex.

Rail plays a critical role in supporting the economy in North America by providing a service that moves raw materials to processing facilities or export terminals, transporting the partially assembled or processed components to factories for completion and transporting final products close to their final destination so that they can be distributed locally. In North America, intermodal rail provides the alternative to point-to-point rail but that special terminal facilities and equipment are required to load or unload the intermodal containers between shipping modes. The greater the number of facilities that exist in a given area, the closer on average freight can move to its final destination. Given the high fixed costs for a full-scale intermodal facility, the purpose of this dissertation is to develop a framework for seeing where such facilities can be economically located. The following is the story of how these issues were researched and addressed.

Since I was a young child I have always been fascinated by maps and big things that moved stuff fast with a special affinity for trains and aircraft. As an undergraduate in the 1990's I developed a keen interest in GIS applications capped off with an undergraduate thesis focused on rail yard site selection. Continuing this theme as a graduate student my Master's thesis research topic continued developing my interest in rail yard site selection using GIS-based multicriteria decision analysis.

In 2005 I moved to Windsor-Essex to work as an Urban Planner and gained my first substantial exposure to the major border crossings between Windsor, Ontario, Canada and Detroit, Michigan, USA. Through my lifelong interest of North American railroads, I was already aware of the rich railroad history in Windsor and Essex County and across the border in the Metropolitan Detroit area. Having never previously entered the USA via a Windsor-Detroit border crossing I was immediately taken aback by the vast number of trucks crossing between the two countries that I observed daily driving past the Ambassador Bridge while commuting to and from work. Through casual observation of truck volumes and freight trains crossing the border it quickly became apparent to me that trucks were the dominant mode of cross-border freight transportation between the two countries.

Through the course of regular business as an Urban Planner, I met Dr. William (Bill) Anderson and Dr. Hanna Maoh from the University of Windsor Cross-Border Institute one day in early 2013. One evening a few weeks later my wife and I were talking and I raised the topic of going back to University to study for a PhD on something related to trains and

GIS. The next day I reached out Drs. Anderson and Maoh and we set up a meeting to explore potential research opportunities. This dissertation marks the capstone of that research and tells the story of the current state of modelling cross-border rail between Canada and the US and opportunities for building on the research in the future.

1.2 Surface Transportation in North America

Shipment by truck dominates the cross-border flow of commodities in both directions between Canada and the United States (Anderson and Coates, 2010; Anderson, 2012; Anderson and Brown, 2012; and Aspila and Maoh, 2014). Given the current nature of North American cross-border supply chains and the removal of many first-mile and last-mile rail services since the development of the United States interstate highway system it is difficult to contest how much of the truck traffic is truly contestable with an intermodal rail linehaul component. An individual truck typically pulling one or two trailers is an inefficient way to move goods over long distances (Eom et al., 2012) when freight trains with three 4400 horsepower diesel-electric locomotives pull over two-hundred intermodal containers loaded on double-stack well cars throughout North America every day. This is an important point to consider given the current political emphasis on globally reducing greenhouse gas emissions and the opportunity for rail intermodal to contribute to in mitigation of the current climate crisis. In 2021 it is now becoming more common to see multiple trains, sometimes as many as 3 combined as 1 with up to a dozen locomotives distributing pulling and braking power throughout these giant consists moving as one large block.

There are some fundamental differences between the surface transportation systems in North America. The highway systems in both Canada and the US are accessible for use by the public including firms at no additional charge though some segments are subject to tolls. Most highways are publicly owned though some are privately maintained and few segments are privately owned and maintained. Depending on the type of highway, these routes are regulated by some combination of federal, state/provincial, regional or local laws. This contrasts with the North American Class I freight rail network that is privately owned and subject to federal regulations. Passenger rail operations in Canada and the United States are subject to federal regulations and some provincial or regional rail operations are subject to corresponding provincial or state laws.

The North American rail network also differs from rail networks in other countries such as Europe where the majority of rail infrastructure is government owned and can be operated on by government railways or privately owned railways though the specifics vary by jurisdiction.

1.3 Transportation Modelling

Most transportation modelling research has focused on passenger trips with an emphasis on commuting between home and place of employment by private automobile. Freight modelling in contrast has been less researched in part due to the complexities involved including the number of actors and the scarce availability of reliable data. Most freight transportation research has focused on the truck mode with relatively little on rail. Additionally, when the geography of freight transportation research is examined there is relatively little for North America compared to Europe or Asia and even less in terms of research about rail transportation. In the North American context there has been very limited research published about cross-border rail transportation between Canada and the US.

There is a wealth of recent research from Europe (Anand et al., 2015; Eng-Larsson and Kohn, 2012; Kordnejad, 2012; Kordnejad, 2014; Monios, 2015; and Woodburn 2003) on topics related to rail and truck/sea intermodal, supply chain management involving rail transportation, sea ports serviced by rail, and modelling of rail or intermodal transportation networks (Assad, 1980; Fernandez et.al, 2004; Ham et. Al, 2005a; Ham et al., 2005b; Kim and Kim, 1985; Kim, 1986; Yan et al. 1995; and You and Kim, 1999). A literature search identified that there is some research in the US context (Ham et al. 2005a; Ham et al., 2005b; Kim et al., 2002; and Lee, 2015). Topics related to the North American cross-border flow of commodities by rail or intermodal are few including Anderson and Coates, 2010; Anderson, 2012; Anderson and Brown, 2012; Aspila and Maoh, 2014 and Park et al., 2014. It is noted that the topic of where to locate intermodal facilities is discussed generally in the researched mentioned above. An overview about the location of intermodal facilities is discussed in Chapter 2 of Monois, 2014. This dissertation research will start to address some of these research literature and knowledge gaps with an emphasis on cross-border flows.

1.4 Rail Transportation Modelling Data Sources

Data sources for modelling rail transportation are limited. This is especially the case in the North American context. As the Class I railroads are privately-owned they are not obligated to make data public unless required by law. There are three primary sources for modelling rail freight in the North American context:

1. The Center for Transportation Analysis at the Oak Ridge National Laboratory. A wide variety of data useful for modelling transportation systems is available

including GIS shapefile data for the historical North American rail network including routes that are no longer in service or have been abandoned.

2. The Bureau of Transportation Statistics at the United States Department of Transportation. A wealth of tabular data is available including trade data by commodity, mode and border crossing for Canada, the United States and Mexico as part of the North American Free Trade Agreement (NAFTA) and the United States Mexico Canada Agreement (USMCA). This data can be tailored to individual research needs using customizable queries or downloaded as part of standardized data releases. The databases storing this data are updated monthly.
3. The Uniform Rail Costing System of the United States Surface Transportation Board. This data set provides a comprehensive description of costs incurred in the operation of Class I railroads in the United States. The data is available in very large tabular formats and is updated typically every 3 years. This information can be adapted for use in analysis of data on a monthly basis as in this dissertation.

It can be deduced based on the information about the primary data sets for modelling rail in the North American context that a very large quantity of data is involved.

1.5 Modelling Rail Transportation

Rail transportation can be modelled at the micro levels which includes identifying which track trains or train cars will travel on, rail yard operations, signalling systems, rail traffic control systems and operation simulations. Modelling rail transportation at the macro level includes modelling flows of people, commodities, trips or tours at regional, national or international scales and has not yet involved the specifics included in micro level modelling.

This dissertation examines modelling rail at the regional-international scale for Canada and the United States using province and state level data assigned to known locations with full-scale intermodal terminals and a customized series of rail network datasets with costs and commodity flows built on framework of a publicly available dataset of the North American rail network. The model developed for the North American context in this dissertation was inspired by the Macro-Economic Network Generation Model (Kim and Kim, 1985) that was used in the development of a strategy to build the South Korean transportation system. The model for the North American context involves two stages:

(i) GIS-based network optimization with route assignment to find the least cost route between terminals *i* and *j* for which the optimized cost becomes the cost to transport goods between *i* and *j* in the second stage; and

(ii) Spreadsheet-based linear optimization.

Stage 1 can be adapted to examine the addition or removal of intermodal terminals or rail network segments and their attributes including quantities or values of commodity flows originating or terminating at intermodal terminals.

Stage 2 can be adapted to examine the introduction, removal or modification of variables and is scalable for potential future modelling needs.

1.6 Dissertation Research Questions and Objectives

Objective #1 is to describe the North American rail network, its history, how it works, connections, flows and the hierarchies of railroads within the Class I rail network. Objective #1 provides the fundamental knowledge required to develop a model that can answer questions about multi-regional commodity flows in the North American context.

Objective #2 is to understand why there is a knowledge gap in modelling rail commodity flows in the North American context. As discussed earlier in this Chapter the research knowledge base for transportation modelling in the North American context is lacking in comparison to other developed economic regions such as those in Europe and Asia. Learning why this knowledge gap exists is valuable for avoiding pitfalls for developing and implementing a multi-regional North American commodity flow model.

Objective #3 is to develop a scalable and adaptable multi-regional commodity flow model for use in the North American cross-border context. Development of a macro-level model for exploring commodity flow and site selection questions at a continental level in North America would be a valuable tool for the research community because it has not yet been achieved. It is noted that the model developed in this research is only intended to be used for cross-border flows and not for domestic flows.

Objective #4 is the development of a scalable and adaptable North American Rail Network dataset. The framework for this type of dataset exists with the data available from the Center for Transportation Analysis at the Oak Ridge National Laboratory. The challenge and opportunity is to build upon the framework with the required attribute data necessary to implement the model developed for Objective #3.

Research Problem #1 is to determine if a full-scale intermodal terminal would be used for cross-border container traffic if one was built in Windsor-Essex? Windsor-Essex is located on the Canadian side of the boundary with the United States across from Detroit, Michigan and hosts multiple border crossing points serving highway, rail, air, sea, and pipeline modes of transport. Presently goods shipped by intermodal rail-truck using trailer on flat car (TOFC) or container on flat car (COFC) are shipped to or from Windsor-Essex by truck to a full-scale intermodal terminal located elsewhere in Ontario or in neighbouring American states.

Research Problem #2 is to determine if a small-scale intermodal technology were introduced into the North American Class I railroad system, would it be used for cross-border container traffic and would Windsor-Essex or other communities without full-scale intermodal terminals benefit from it? Since the introduction of regular TOFC and COFC intermodal services on Class I railroads there have been several small-scale technological advances. Would the introduction of a recent technological advance in Europe impact the delivery of intermodal services in the North American context? In the following chapters of this dissertation, these objectives and research problems are explored.

1.7 Dissertation Outline

This dissertation is organized as follows:

Chapter 2 provides a high-level overview of the history of Class I railroads in North America. Included are descriptions of the 7 freight hauling Class I railroads in Canada and the United States, an overview of their predecessors, how they work, connections with other Class I railroads, flows and a summary of their partnerships with other carriers. Chapter 2 addresses Objective #1 of this dissertation.

Chapter 3 describes the formulation, data and the implementation of the model for modelling multi-regional rail commodity flows in the North American context. Included are a literature review, discussion about using a network analysis and a linear programming approach in the model, the history of the Kim and Kim (1985) model, a detailed overview of the data used in the Multi-Regional North American Rail Commodity Flow model, and implementation of the model. Chapter 3 addresses Objectives #2, #3 and #4 of this dissertation.

Chapter 4 investigates Research Problem #1, if a full-scale intermodal terminal was built in Windsor-Essex, would it generate enough international container lifts to justify its fixed and operational costs? This chapter includes discussion about full-scale intermodal terminals and provides an overview of the economic drivers in Windsor-Essex. There is discussion about the baseline scenario modelling rail commodity flows between Canada and the US for the month of June 2017 and a modification of the dataset and model to examine the hypothetical scenario of a full-scale intermodal terminal in Windsor-Essex.

Chapter 5 investigates Research Problem #2, exploring two scenarios where a small-scale intermodal technology is introduced to the North American context. This chapter provides an overview of the Megaswing intermodal rail car technology, originally developed in the 1990's, deployed in Sweden in the 2000's and currently deployed in regular service between Germany and Austria. A hypothetical scenario is explored replacing existing full-scale intermodal terminals with the small-scale intermodal technology at small and mid-sized regional centres in Ontario.

Chapter 6 summarizes this dissertation and includes an examination of the objectives and research problems achieved, contributions to scholarly research, opportunities to extend this research and final remarks.

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CHAPTER 2

NORTH AMERICAN RAIL NETWORK

2.1 Introduction

The North American rail network began in the 1830’s with the first railroads built near the Atlantic Ocean along waterways to transport people and goods to and from local centres. During the 1830’s through 1850’s the railroad network grew from the Atlantic coast westward to the Great Lakes and the Mississippi River and eastward from Pacific Ocean ports to resource areas further inland. In 1862 the Union Pacific was chartered to build a railroad from the Mississippi River westward and meet with the Central Pacific building eastward from Sacramento, California to create an east-west transcontinental railroad across the United States of America. In 1881 the Canadian Pacific was incorporated to build a Canadian transcontinental railroad east from Vancouver BC and west from the existing railroad connection near North Bay, ON. The North American Rail Network expanded until the early 1950’s when it faced growing competition with emerging airlines for passenger travel and the developing Interstate Highway System for both freight and passenger travel.

Through the 1960’s and 1970’s many railroads faced financial distress attributed to US Federal Government regulations and the competing Interstate Highway System that led to a series of mergers including the New York Central and Pennsylvania Railroad in the northeast merging to become the ill-fated Penn Central which subsequently failed and together with several other eastern railroads including the New Haven, Erie-Lackawanna, Lehigh Valley, Reading Lines and Central of New Jersey to be consolidated under the name Conrail. The Seaboard Air Line and Atlantic Coast Line in the southeast to become the Seaboard Coast Line which subsequently merged with the Louisville & Nashville and the Clinchfield to operate under the banner of the Family Lines System. The Chessie System was created with the merger of the Chesapeake and Ohio, the Baltimore and Ohio and the Western Maryland railroads which generally served the central Atlantic Coast through the Midwest. The Illinois Central and Gulf, Mobile & Ohio along the east side of the Mississippi River merging to become the Illinois Central and the Norfolk & Western absorbing the Wabash in the Midwest. In the northwest and Midwest, three of the four large railroads, the Chicago, Burlington & Quincy, the Great Northern and the Northern Pacific merged under the banner of the Burlington Northern. The fourth large railroad in the northwest, the Chicago, Milwaukee, St. Paul & Pacific, more commonly known as the "Milwaukee Road" ceased all operations west of North Dakota to Seattle and Tacoma WA. These mergers and acquisitions and the subsequent deregulation of the American railroad industry in 1980 created the foundation for the current seven Class I Railroads operating in Canada and the USA.

2.2 Current Canadian and American Class I Railroads

A Class I Railroad is defined by the US Department of Transportation Federal Railroad Administration (FRA) as a railroad with operating revenues of $490 million USD or more (United States Department of Transportation Federal Railroad Administration, 2020). There are 7 freight railroads operating in the USA that are considered to be Class I Railroads: BNSF Railway Co., Canadian National Railway, Canadian Pacific, CSX Transportation, Kansas City Southern Railway Co., Norfolk Southern Combined Railroad Subsidiaries, and Union Pacific Railroad Co. (United States Department of Transportation

Federal Railroad Administration, 2020). The combined revenue of all freight railroads operating in the USA in 2017 was approximately $80 billion USD with approximately $67 billion USD in revenue generated by the 7 Class I Railroads (United States Department of Transportation Federal Railroad Administration, 2020). The 7 Class I Railroads operate as independent systems and as part of a larger North American transportation system. It should be noted that a proposed merger between the Canadian National Railway and Kansas City Southern Railway Co. has been proposed and is subject to the regulatory approval process in the United States of America. Figure 2.1 includes a map showing the routes of all Canadian and American Class I Railroads.

Source (Class I Railroads): Oak Ridge National Laboratory, adapted by author.
Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

Figure 2.1 – Class I Railroads: Canada and USA (not all lines shown)

2.2.1 BNSF Railway Co. (BNSF)

BNSF was formed in 1995 in a merger between the Burlington Northern and the Santa Fe railroads. It primarily serves the western USA and has over 24,000 miles of track and 8,000 miles of trackage rights. BNSF has international connections to Canada with trackage and trackage rights in and around Vancouver BC and has trackage rights over CN to Winnipeg MB (Wilson and Rehberg, 2014, BNSF Railway, 2020).

The primary cargo hauled by BNSF is intermodal containers. Approximately 2/3 of the daily 70-90 trains between California and the major terminals of Chicago IL, Kansas City MO, Memphis TN and Fort Worth TX are dedicated or a combination of Container-On-Flat-Car (COFC) or Trailer-On-Flat-Car (TOFC). BNSF also has heavy intermodal traffic flow on its routes between Chicago IL and Fort Worth TX, Chicago IL and Seattle WA, and Chicago IL and Portland OR. BNSF has connections with all other Class I Railroads in Kansas City MO and connections with all other Class I railroads except the Kansas City Southern in Chicago IL (Wilson and Rehberg, 2014, BNSF Railway, 2020). See Figure 2.2.

A planned merger between BNSF and Canadian National in 1999 was called off in 2000 following anticipated objection by other railroads and the USA Government. BNSF and Canadian National have continued as friendly Class I competitors since the abandoned merger and offer interlining opportunities at several major terminals for origins and destinations on routes between the western USA and Canada.

Source (Class I Railroads): Oak Ridge National Laboratory, adapted by author.

Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

Figure 2.2 – BNSF Routes (not all lines shown)

2.2.2 Canadian National Railway (CN)

CN was formed by the Canadian Government in 1919, taking control of several financially troubled railroads that resulted in the creation of a cross-Canada railroad network from the Atlantic Ocean to the Pacific Ocean with subsidiary American railroads branching into the midwestern and northeastern USA. CN operated as a Crown Corporation in Canada until it was privatized in 1995. Following privatization, CN sold off or abandoned many unprofitable routes and embarked on a period of major expansion in the USA and western Canada including the acquisition of the Illinois Central in 1998, the Wisconsin Central in 2001, the Bessemer and Lake Erie in 2003, the Duluth, Missabe and Iron Range in 2003, the Elgin, Joliet and Eastern in 2005, and BC Rail in 2005. CN uses major intermodal facilities in Vancouver BC, Prince Rupert BC, Edmonton AB, Winnipeg MB, Toronto ON, Montreal QC, Halifax NS, Superior WI, Chicago IL, Memphis TN, Jackson MS and Mobile AL. Currently CN is constructing a large intermodal seaport in Quebec City QC. (Canadian National Railway Company, 2020) The CN system has over 20,000 miles of track including trackage rights on Canadian Pacific, CSX Transportation, Kansas City Southern and Union Pacific. CN's system is generally an east-west oriented system across Canada with a north-south route from Chicago IL to the Gulf of Mexico (Wilson and Rehberg, 2014, Canadian National Railway Company, 2020). See Figure 2.3.

Source (Class I Railroads): Oak Ridge National Laboratory, adapted by author.

Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

Figure 2.3 – CN Routes (not all lines shown)

2.2.3 Canadian Pacific (CP)

CP was incorporated in 1881 to become Canada's first transcontinental railroad with its main line running from St. John NB on the Atlantic Ocean to Vancouver BC via Montreal QC, Ottawa, ON, Sudbury ON, Thunder Bay ON, Winnipeg MB, Regina SK and Calgary AB. CP expanded its routes in both Canada and the USA in the late 19th Century through to the 1960's including an American subsidiary known as the "Soo Line" that operates throughout the US Midwest although now known by the parent company's name, as well as Canadian routes throughout southern Ontario, southern Quebec and the prairie provinces. In 1991, CP expanded in the eastern USA through the acquisition of the financially troubled Delaware and Hudson to provide connections or interlining with east coast centres. In 1994, CP made a decision to focus on its western routes and American connections and sold off or abandoned all trackage east of Montreal QC including its connections to the Atlantic Canada deep water port in St. John NB. As of 2019, CP has initiated plans to reacquire this route to St. John NB to provide an intermodal container service from the Atlantic Ocean. In 2009, CP made a major American acquisition with the purchase of the regional Dakota, Minnesota & Eastern (DM&E) to access western USA coal fields. The DM&E was comprised of former Union Pacific predecessor Chicago & North Western routes between the Midwest and South Dakota (Wilson and Rehberg, 2014, Canadian Pacific, 2020).

CP has major intermodal terminal facilities in Vancouver BC and Montreal QC. The major international connections for CP are in Vancouver BC with BNSF, Eastport ID with Union Pacific, Duluth and Minneapolis MN with BNSF, Buffalo and Binghamton NY with CSX Transportation and Norfolk Southern, Detroit MI with CSX Transportation and Norfolk

Southern and Chicago IL with BNSF, CN, CSX Transportation, Norfolk Southern and Union Pacific. CP uses trackage rights on CN, Norfolk Southern and BNSF. CP's system is generally an east-west route with few branches. See Figure 2.4.

Source (Class I Railroads): Oak Ridge National Laboratory, adapted by author.

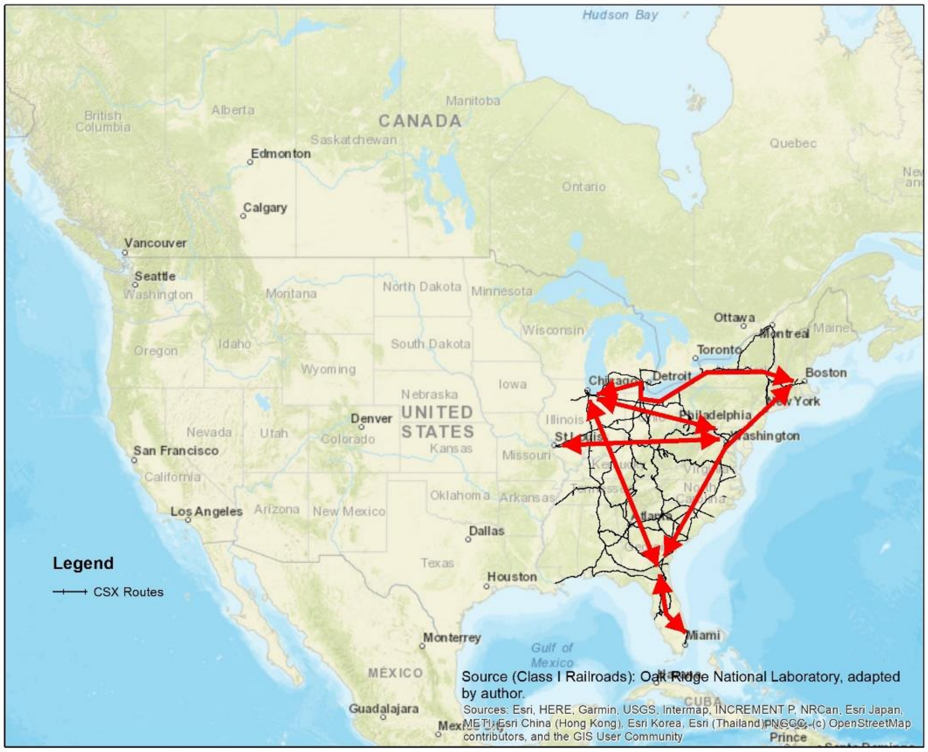
Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

Figure 2.4 – CP Routes (not all lines shown)

2.2.4 CSX Transportation (CSX)

CSX was incorporated in 1986, formalizing the merger of the Chessie System and the Family Lines System, serving routes primarily located in the southeastern USA. In 1997 CSX acquired approximately 40% of Conrail's assets resulting in a major expansion of its network to the northeastern USA. Historically, CSX and its predecessor routes served as a major eastern USA coal hauler.

Major terminals served by CSX include Chicago IL, St. Louis MO, New Orleans LA, Buffalo NY, Cleveland OH, Detroit MI, Baltimore MD, Atlanta GA, Miami FL and seaports at Miami FL, Philadelphia PA, Portsmouth VA and Wilmington NC. In 2013 CSX launched a major expansion project on its "National Gateway Corridor" between Baltimore MD and Greenwich OH with connections to Chicago IL to expand clearance heights so that it could serve as the primary double-stack intermodal route from the USA's east coast (Wilson and Rehberg, 2014, CSX Transportation, 2020). See Figure 2.5.



Source (Class I Railroads): Oak Ridge National Laboratory, adapted by author.

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Figure 2.5 – CSX Routes (not all lines shown)

2.2.5 Kansas City Southern Railway Co. (KCS)

KCS was organized in 1900 as a north/south route between Kansas City MO to Texas destinations with connections to Mexico. This railroad was unique from the perspective that at the time because most American railroads were looking to connect the middle of the continent to the Atlantic or Pacific coasts. In 2005 KCS acquired Mexican routes and established them under the name Kansas City Southern de Mexico (KCS de M). The acquisition of Mexican routes now offered a direction connection between Chicago IL and Kansas City MO with ports on the Mexican Pacific and Gulf of Mexico.

The KCS is a 6,000+ mile north/south route with several branches. Intermodal COFC is the primary cargo followed by cargo related to the automotive industry. KCS has major terminals in Kansas City MO, Jackson MS, New Orleans LA, Dallas TX, Houston TX, Veracruz Mexico and Lázaro Cárdenas Mexico (Wilson and Rehberg, 2014, Kansas City Southern, 2020). See Figure 2.6.

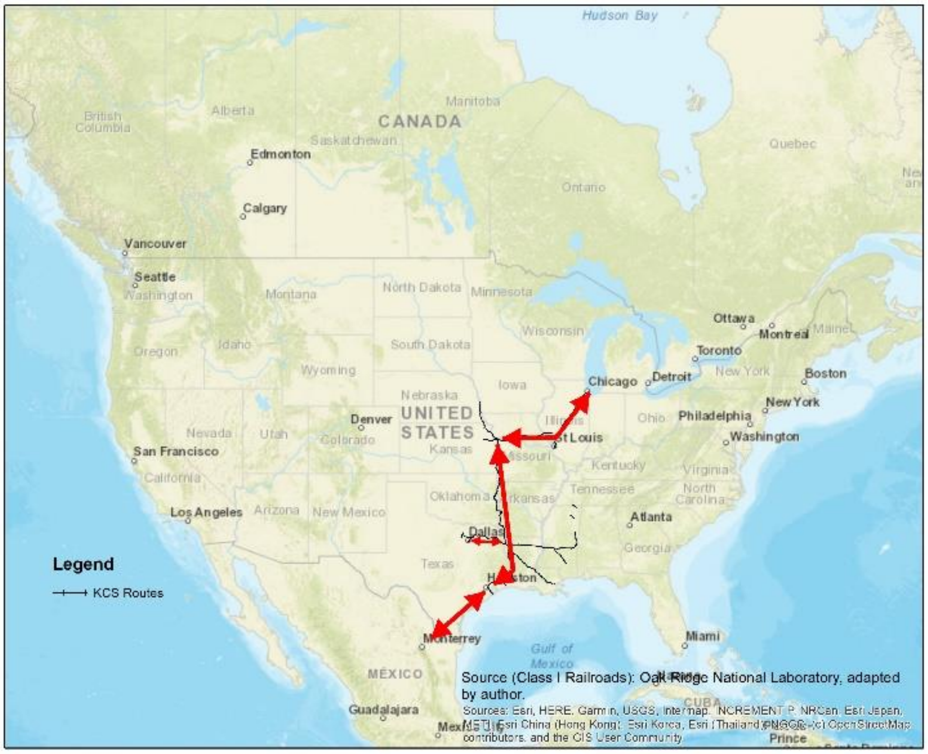

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Figure 2.6 – KCS Routes (not all lines shown)

2.2.6 Norfolk Southern Combined Railroad Subsidiaries (NS)

NS was formed by the consolidation of the Norfolk & Western and Southern railways in 1982. This resulted in a system that served most major centres in the Midwest and southeast USA. In 1998, NS acquired approximately 60% of Conrail in a deal that provided NS with routes that served most of the northeast USA and a valuable land bridge intermodal route between Philadelphia PA, Newark NJ and Chicago IL. See Figure 2.7.

The two primary types of cargo on the NS are commodities and intermodal COFC. NS has major intermodal facilities in Philadelphia PA, Newark NJ, Memphis TN, St. Louis MO, New Orleans LA, and Atlanta GA. Over the first two decades of the 2000's, NS has made capital improvements to its facilities at the port of Norfolk VA and its route between Norfolk VA and Columbus OH to expand double-stack intermodal services for destinations and connections at Detroit MI, Cleveland OH, Kansas City MO and St. Louis MO. Additional capital improvements have been made at the intermodal facilities at the Port of Savannah, GA (Wilson and Rehberg, 2014, Norfolk Southern Corp., 2020).

Source (Class I Railroads): Oak Ridge National Laboratory, adapted by author.

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Figure 2.7 – NS Routes (not all lines shown)

2.2.7 Union Pacific Railroad Co. (UP)

The UP was chartered in 1862 to build the segment of a transcontinental railroad west from the Mississippi River to meet up with the Central Pacific Railroad that was building east from Sacramento CA. The UP is the longest continuous operating railroad in North America. The UP system has grown substantially since the 1980's through mergers and acquisitions of the Missouri Pacific, Western Pacific, Southern Pacific/Denver & Rio Grande Western (including the original Central Pacific Railroad), the Missouri-Kansas-Texas and the Chicago & North Western (Wilson and Rehberg, 2014, Union Pacific, 2020).

Major ports and intermodal facilities served by UP include Los Angeles/Long Beach CA, Oakland CA, Seattle WA, Houston/Galveston TX, New Orleans LA, Kansas City, MO and Chicago IL. The primary Canada-USA border crossing point for the UP is the interline connection with CP at Eastport ID. UP connects with the other Class I Railroads in Kansas City MO, and with all except KCS at Chicago IL. UP also has connections with the eastern Class I Railroads in St. Louis MO. See Figure 2.8.

Source (Class I Railroads): Oak Ridge National Laboratory, adapted by author

Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

Figure 2.8 – UP Routes (not all lines shown)

2.3 How the Freight Rail Network Works

The North American rail network functions as a hub and spoke network with a predominately east-west orientation. Cargo transported on the North American rail network typically also travels by truck or by sea and truck. This depends on several variables such as the type of commodity being transported, where and how production occurs and where and how consumption occurs. In 2017 over $93 billion (USD) in goods were transported between Canada and the USA. (US DOT Bureau of Transportation Statistics, 2020). The Class I Railroads have developed partnerships with other shippers including other railroads, trucking companies, ocean shippers and logistics parks. As is the case with most shipments the “Last Mile Problem” (Rodrigue et al., 2009) applies to the freight rail network in most cases as the cargo has to be loaded or transloaded onto rail cars at the rail origin or destination. The mode for the last mile is dependent on the type of commodity. Bulk cargo such as certain types of agricultural commodities and mineral commodities may be transferred directly between rail cars and ships or may transferred from a rail car or ship via a temporary storage facility such as a grain elevator, storage tank or an open pile. In the case of major seaports such as Los Angeles / Long Beach or Vancouver BC, standard 20’ or 40’ sea containers or the less common 45’ sea container may be unloaded from the ship and then drayed by truck to a transloading warehouse where the cargo is unloaded from the sea container and loaded into a 28’, 48’, 53’ or 60’ container. The purpose for such as transload could be customer specific for delivery at a destination such as a retail store, could be to reduce the number of containers used to transport the same amount of cargo, or could be motivated by the tight market for truck drivers.

Almost all of the Class I Railroads operate east-west over a large section of North America with connections from one coast to the central part of the USA, with the exception of CN which operates from Pacific to Atlantic and the Gulf of Mexico and KCS which operates north-south along the centre of the US through to Mexico. There are 5 key Class I Railroad interchange points most notably Chicago IL and Kansas City MO, followed by St. Louis MO, Dallas-Fort Worth TX and Shreveport LA. See Figure 2.9. Chicago IL functions as the primary North American freight rail interchange point for traffic originating or terminating at locations throughout Canada, the USA and Mexico in addition to being a key transloading point and intermodal COFC/TOFC transfer point with trucking companies. Kansas City MO is widely regarded as the second busiest freight trail interchange point in the USA. At a key geographic location in the centre of the USA Kansas City MO offers less congestion than the rail facilities in Chicago IL and provides connections to/from Pacific ports with eastern Canada, the eastern USA and Mexico.

St. Louis MO, located on the Mississippi River is an eastern terminus of the BNSF and the UP, a western terminus of the CSX and NS and is an interchange point on CN’s former Illinois Central north-south corridor with connections to the Gulf of Mexico. The location is used for interlining opportunities as well as connections to major intermodal facilities in Memphis TN. Dallas-Fort Worth TX has connections with multiple BNSF and UP lines and serves as an interlining point with the KCS for connections to and from Mexico. Shreveport LA, located in northwest LA serves as an interchange point between BNSF, CN, KCS and UP. Shreveport provides connections along CN and KCS’ north-south corridors to and from Mexico as well as connections to central and eastern Gulf of Mexico ports via connections with CN an further interchange with the CSXT and NS for origins and destinations in the southeast USA.

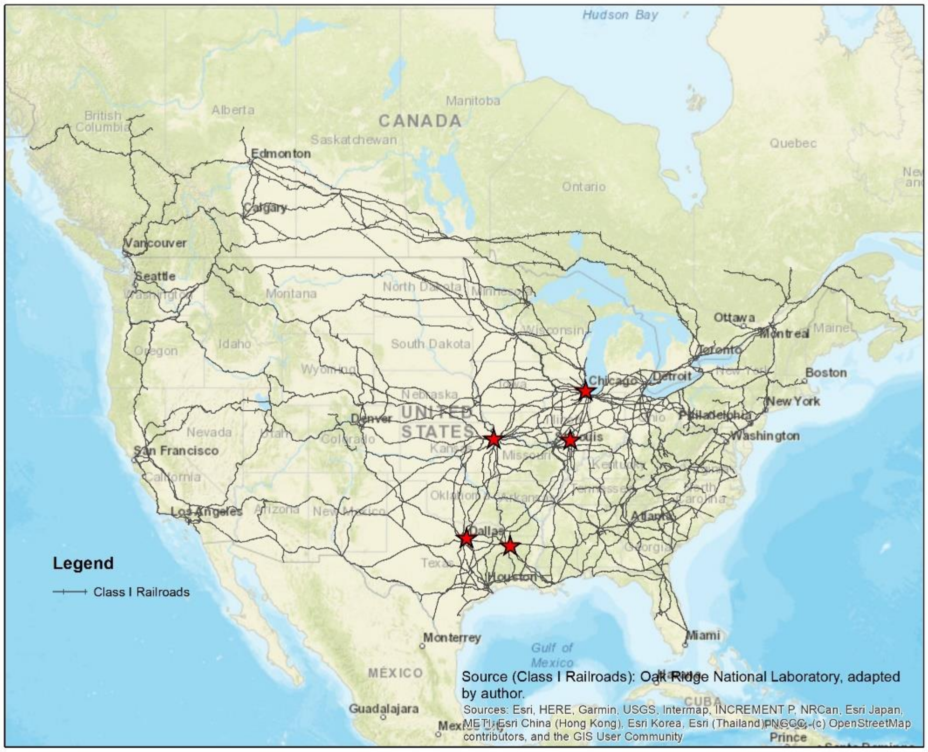

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Figure 2.9 – Key Class I Railroad Interchange Points

2.4 Commodity Flows Across the North American Railroad Network

There are data for 99 commodity group flows between the North American Free Trade Agreement (NAFTA) / United States Mexico Canada Agreement (USMCA) agreements by the respective governments of the USA, Canada and Mexico and reported by the United States Department of Transportation Bureau of Transportation Statistics (USDOT BTS), (USDOT BTS, 2020). These 99 commodity flow groups can be aggregated into 16 commodity flow groups for ease of analysis and reporting. See Table 2.1.

Table 2.1 - USDOT BTS Commodity Flow Groups

Commodity Groups	Description
01-05	Animal & Animal Products
06-15	Vegetable Products
16-24	Foodstuffs
25-27	Mineral Products
28-38	Chemicals & Allied Industries
39-40	Plastics / Rubbers
41-43	Raw Hides, Skins, Leather & Furs
44-49	Wood & Wood Products
50-63	Textiles
64-67	Footwear / Headgear
68-71	Stone / Glass
72-83	Metals
84-85	Machinery / Electrical
86-89	Transportation Equipment
90-97	Miscellaneous
98-99	Service

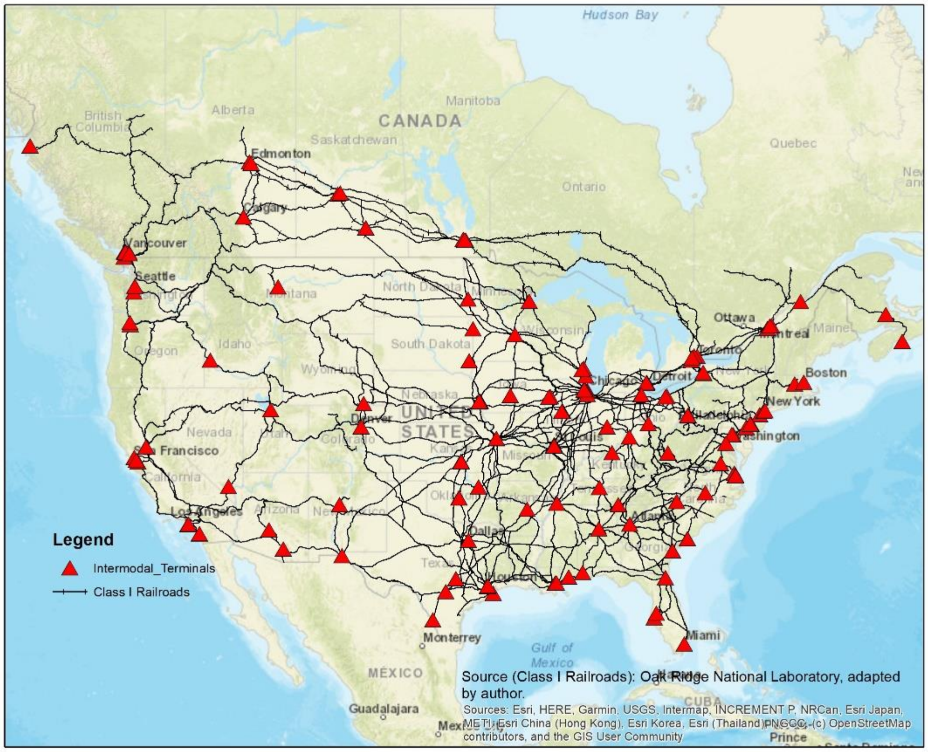
Table 2.2 shows a small sample subset of the data.

Table 2.2 – Sample of USDOT BTS Commodity Flow Data

TRDTYPE	USASTATE	COMMOD	DISAGMO	MEXSTATE	CANPROV	COUNTRY	VALUE	SHIPWT	FREIGHT_	DF	CONTCOD	MONTH	YEAR
1	MI	87	5		XA	1220	321070	0	5375	1	X	6	2017
1	MI	87	5		XA	1220	113617	0	3471	2	X	6	2017
1	MI	87	5		XB	1220	198741	0	6756	1	X	6	2017
1	MI	87	5		XB	1220	3798	0	168	2	X	6	2017
1	MI	87	5		XC	1220	1118919	0	16635	1	X	6	2017
1	MI	87	5		XC	1220	18964	0	296	2	X	6	2017
1	MI	87	5		XM	1220	1787558	0	34475	1	X	6	2017
1	MI	87	5		XM	1220	437704	0	10140	2	X	6	2017
1	MI	87	5		XO	1220	7.25E+08	0	9795241	1	X	6	2017
1	MI	87	5		XO	1220	57219084	0	815618	2	X	6	2017

As shown in Figures 2.2 through 2.8 the North American Railroad Network generally is oriented for east/west flows to or from production/consumption centres and Pacific or Atlantic ports. The notable exceptions to this are shown in Figures 2.3 and 2.6 where CN and KCS have north/south corridors along the centre of the USA generally connecting the east/west American and Canadian Class I Railroad systems at Chicago IL and Kansas City MO to origins and destinations in Canada and Mexico.

There are rail intermodal facilities located on Class I Railroads throughout most of the Canadian Provinces and American States. Figure 2.10 – Intermodal Facilities shows the location of the larger facilities.



Source (Class I Railroads): Oak Ridge National Laboratory, adapted by author.

Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

Figure 2.10 – Intermodal Facilities

The distance between origins and destinations is one of the factors in deciding how cargo will be shipped. It is generally considered that rail is a viable option for land shipments with distances greater than 500 miles or 800 kilometres between origin and destination with highway being the preferred mode for most shipments of less than 500 miles or 800 kilometres. A contributing factor for why rail is more common for longer distance than shorter distance surface intermodal shipments is the spreading of the fixed cost of intermodal transfer over larger distances. Table 2.3 displays the distance in miles by the Class I Railroad Network for select locations between Canada and the USA.

Table 2.3 – Distances (miles) by Class I Railroads for Select Locations Between Canada and the USA.

	Calgary AB	Edmonton AB	Halifax NS	Prince Rupert BC	Montreal QC	Toronto ON	Vancouver BC	Windsor ON	Winnipeg MB
Atlanta GA	2282	2351	2029	3290	1269	964	2921	722	1557
Baltimore MD	2424	2494	1452	3432	716	677	3063	694	1699
Buffalo NY	2076	2078	1199	3017	439	132	2716	261	1276
Chicago IL	1572	1642	1586	2581	826	521	2211	290	847
Cleveland OH	1895	1965	1377	2904	618	311	2534	166	1170
Dallas -Ft Worth TX	2076	2164	2463	3103	1704	1398	2481	1157	1495
Detroit MI	1833	1903	1317	2842	557	252	2473	10	1109
Duluth MN / Superior WI	1195	1170	2065	2109	1305	1000	1834	769	376
Gulfport MS	2483	2572	2397	3511	1638	1332	3013	1091	1806
Halifax NS	3063	3030	0	3969	760	1090	3702	1306	2229
Houston TX	2322	2410	2569	3349	1809	1504	2713	1262	1741
Kansas City MO	1731	1819	1793	2758	1034	728	2343	487	1098
Los Angeles / Long Beach CA	1848	2051	3770	2351	3010	2705	1431	2472	2503
Memphis TN	2024	2112	2026	3051	1267	961	2560	720	1346
Miami FL	2967	3037	2578	3975	1843	1649	3606	1407	2242
Minneapolis MN	1147	1235	1993	2174	1233	928	1786	697	518
Mobile AL	2420	2508	2326	3447	1566	1261	2972	1020	1742
New Orleans LA	2413	2501	2402	3440	1643	1337	2942	1096	1736
Newark NJ	2443	2513	1345	3452	610	567	3082	697	1711
Norfolk VA	2533	2603	1873	3542	1138	1089	3173	847	1809
Philadephia PA	2384	2454	1359	3393	623	585	3023	655	1659
Portland OR	868	1050	3751	1250	2991	2679	330	2470	1522
Portsmouth VA	2536	2606	2158	3545	1398	1092	3175	851	1811
Savannah GA	2558	2628	2082	3567	1346	1200	3197	958	1833
Seattle WA	759	870	3713	1070	2954	2641	150	2433	1484
St Louis MO	1735	1823	1798	2762	1038	733	2350	491	1103
Wilmington NC	2438	2508	1832	3447	1096	994	3077	753	1713

2.5 Summary

The Class I Rail Network in Canada and the USA has grown substantially since the first railroads were built in the 1830’s. It has reached its current state of 7 Class I Railroads through a major period of mergers and acquisitions in the 1960’s and 1970’s. In 1980 deregulation of rail pricing in the USA led to a period of recovery and new competition between the railroads in the 1980’s. In the 1990’s and early 2000’s a new period of mergers and acquisitions led to the current 7 Class I Railroads: BNSF, CN, CP, CSX, KCS, NS and UP.

The Class I Rail Network is generally divided into the 2 Canadian roads – CN and CP, the two western American roads – BNSF and UP, the two eastern American Roads, CSX and NS, with north-south corridors operated by CN and KCS that generally follow the Mississippi River down the center of the USA from Chicago IL to Louisiana and on to

Mexico. Cargo generally flows east/west and there are 5 key Interchange Points located at Chicago IL, Kansas City MO, St. Louis MO, Dallas-Fort Worth TX and Shreveport LA.

International commodity flows between the NAFTA/USMCA countries are reported monthly on the USDOT BTS website and are available for 99 commodity groups. The data show the quantity and value of shipments between each of the states/provinces in the NAFTA/USMCA countries and could be used to model freight flows by rail.

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CHAPTER 3

MODELLING CROSS-BORDER RAIL FREIGHT

3.1 Introduction

There has been relatively little research on modeling freight transport (Ortúzar and Willumsen, 2011), with even less published on freight rail transport in the North American context relative to truck transport. Modeling freight is more difficult than modeling passenger movements because of the number of actors involved including firms, shippers, carriers, potentially custom brokers and others with potentially conflicting interests (Ortúzar and Willumsen, 2011). These actors may be involved in individual, coordinated, overlapping, aligned or conflicting supply chains. In the case of this problem, the only actor involved is the Class I railroads so it should be easier to solve. While the Class I railroads may have prepared research on freight rail, it is likely protected as intellectual property or trade secrets and not shared publicly for competitive reasons. This presents an opportunity to explore commodity flows by rail and modeling of the same.

Logistics development studies produced by planning departments and regional development agencies have not generally used a network analysis approach. Examples of such studies include the Twin Ports Intermodal Freight Terminal Study by the Midwest Regional University Transportation Center et al. (2003), Intermodal Opportunities in the Appalachian Region by the Rahall Transportation Institute, Marshall University and Wilbur Smith Associates (2004), CenterPoint Intermodal Center – Elwood by the Urban Land Institute (2008), the Salinas Valley Truck to Rail Intermodal Facility Feasibility Study by TranSystems (2011), Freight Intermodal Connectors Study by the USDOT

Federal Highway Administration (2017), Vaughan Intermodal Terminal by Cando Rail Services (undated), and Converting Detroit City Airport into an Intermodal Freight Handling Facility by Klinkert (undated). Opportunities exist to improve the location of logistics facilities using models that include analysis of transportation networks. Using a network model approach results in information that describes what commodities and in what quantities flow to or from locations or what commodities flow through locations on the network. An advantage of this approach is informed decisions can be made about where to pursue or not pursue the acquisition of land for both intermodal facilities and land uses that will benefit from close proximity to intermodal facilities.

A number of previous input-output models and transportation models led to the adaptation of the Kim and Kim model (1985) as it is applied in this dissertation. It is noted that the input-output component of the Kim and Kim model (1985) is not included in the adapted model as the South Korean scenario that they examined considered production facilities whereas the model considered in this dissertation excludes the production component and uses adapted versions of the transportation system and intermodal terminal / port system components. These previous models include Leontief (1936); Interregional Input-Output Models by Isard (1951), Leontief (1953) and Moses (1955); the Commodity Flow Model by Leontief and Strout (1963); Gravity Models by Carroll and Bevis (1957), Schneider (1959) and Isard (1960); Entropy Maximization by Wilson (1969); and Kim et al. (1983).

The Kim and Kim model was later adapted and deployed with additions that addressed density of land use with transportation congestion costs on networks of various transportation modes (Kim, 1986). The urban and regional activity models based on Kim's work and their foundations have been adapted or incorporated into several models including an urban activity land use model by Rho and Kim (1989); a combined transportation and input-output model by Kim et al. (2002); modeling changes to transportation networks following unexpected disruptions by Sohn et al. (2003) and Danczyk et al. (2017); combined interregional multimodal commodity and transportation network flows by Ham et al. (2005b); travel time forecasting by You and Kim (2007). In the last 10 years the model has been adapted further to study trip distribution by de Grange et al. (2010); alternative paths-search algorithm by Jeong et al. (2010); national interstate input-output model by Park et al. (2011); reliability-based land use and transportation optimization by Yim et al. (2011); multi-regional inoperability input-output by Pant et al. (2011); interregional commodity flows with network autocorrelation in spatial interaction models by Chun et al. (2012); optimal hierarchical decision models for regional logistics networks by Zhang et al. (2014); bi-national local economic model for international freight movements by Park et al. (2014); simultaneous estimation of physical and commodity flows by Többen (2017); metropolitan economic and logistics development by Lan et al. (2017).

In the early 2000's the model was adapted and used to propose strategic management and regional recovery efforts from a hypothetical disaster in the Midwest region of the United States that impacted regional transportation networks and interregional commodity flows (Kim et al. 2002; Ham et al. 2005a; Ham et al. 2005b). In these cases, a two-step model was deployed using simplified road and rail networks based on the United States Department of Transportation's 1997 National Transportation Atlas Database with the transportation network modeling component calculated similar to Kim and Kim (1985) and equilibrium models building on Wilson's work in the late 1960's and early 1970's (Kim et al. 2002) and an integration of models developed by Leontief, Strout and Wilson (Ham et al. 2005a and Ham et al. 2005b).

A major obstacle for exploring rail freight in the North American context is that all Class I railroads are privately owned and use private infrastructure. All the infrastructure and equipment serves a purpose, regardless of whether it is the tracks that the trains travel on to get from an origin to destination, the yards where equipment is sorted, assembled or stored, the terminals where goods or people are loaded or unloaded from the trains, the track connecting the yards and terminals, the locomotives or rolling stock the make up each train or the operations, maintenance and repair facilities that maintain all of the infrastructure. Each of these elements are used to facilitate the transport of commodities for the railroads to generate revenue and maximize profits.

Different than the trucking industry that uses publicly funded highway systems with over 111,600 route segments (Center for Transportation Analysis, 2015) the privately owned Class I railroad network comprises approximately 12,900 track segments in Canada and the USA. While 12,900 track segments present a large number of routing options for railroads, it contains substantially fewer segments than the 111,600 segment highway system and an exponentially smaller number of potential route options. The behaviour of users on a privately funded and maintained rail system could be expected to be more regimented and predictable than a very large publicly funded highway system although the firms that operate on these respective systems have the same performance goals of generating revenue and maximizing profits. Additionally, the privately owned and operated rail system inherently presents an additional problem of how to obtain origin and destination data for rail shipments as waybill information is not typically in the public domain and there is very little incentive for the firms to provide such information. In the case of privately funded rail systems congestion is a choice variable that resolves itself by limiting use based on the decisions of the network's owner. This could include maximizing throughput by operating at less than free flow speeds. This is unlike congestion issues that are prevalent on publicly funded transportation systems such as highways where anyone who owns a vehicle can use the system.

There are only 7 Class I railroads carrying freight in North America which would make the exercise of identifying which railroads haul which commodities and in what quantities between origin and destination pairs relatively straight-forward if the commodity flow data were publicly available considering that ownership of the rail route segments and trackage rights information is in the public domain (Center for Transportation Analysis, 2015). Given that trucks haul over 57% of the cross-border trade between Canada and the USA by USD value (US DOT Bureau of Transportation Statistics, 2018, March 16) and there are an enormous number of potential routing options, it is not surprising that some truck GPS data is available for research purposes.

The transportation of freight is inherently complex considering the number of routing options and the number of actors involved. For the purpose of this research, a rail-only scenario is used with an option in the model for the first-mile/last-mile logistics to/from the rail terminal that is typically transported by truck. In the case of this research, the first-mile/last-mile option is modelled in the network to represent drayage between full-scale intermodal terminals in Ontario, Canada and Ontario Economic Regions. Also, global supply chains are indirectly factored in as large quantities of commodities are shipped through major intermodal facilities at seaports though are not explicitly modelled. Given the commodity flows between origin and destination terminals, the problem at hand for the case of a rail-only scenario becomes to first select the most efficient combination of Class I railroad routings based on a hierarchy of the Class I railroads and their cost. Next a linear optimization problem is formulated where the selected routes and their costs are used in conjunction with the commodity flows and terminal characteristics to determine if a terminal has proper capacity to handle the flow of commodities or will require expansion. The model will also determine the optimal amounts that will undergo drayage from the modeled terminal to serviced markets.

It is acknowledged that not all commodities are shipped by rail intermodal and that for some it may not be practical without substantial innovations to intermodal equipment used in North America. Consider the most common types of intermodal containers are standardized metal boxes designed for use on ships, trains and trucks. There are also standardized cylindrical tanks that have been built into typically a 20-ft intermodal container frame, though these are primarily used for specialty chemicals rather than transporting larger quantities of liquified chemicals that are transported by rail tank cars, tanker trucks, pipelines or ships. More recently it has been observed that individual automobiles have been shipped on special intermodal frames within the United States. (BNSF, 2021) While this is not typical in North America as automobile parts and components are typically shipped on standard flat cars or box cars and finished automobiles are typically shipped by rail on special 2 or 3 level 89-foot flat cars. While some agricultural commodities are being containerized for transport, the majority are shipped by rail in covered hoppers. The same is the case for pelletized commodities used in manufacturing and chemical processing industries. Aggregates, ores and mineral raw materials are currently transported in open or covered hoppers subject to the commodity. Future innovations in rail car technology may make it possible to use a standardized freight rail car for the transportation of all commodities in an intermodal container or trailer. As described in the following sections, the model used in this dissertation functions under the assumption that all commodities can or are shipped intermodally. Using this assumption it needs to be recognized that the results may be more imprecise than if all commodities were actually shipped by rail using intermodal. Given that this dissertation is a foundational study in the North American context the assumption is deemed to be tolerable so that a baseline can be established for future research.

3.2 The Model

A linear programming approach has been taken to model cross-border rail between Canada and the USA. The primary purpose of this model is to generate information that can be used to determine the feasibility of adding an intermodal terminal to a location on the rail system. This approach takes origin-destination flows as exogenous and prices as fixed, which justifies minimizing costs rather than profit maximization. The inspiration for this model comes from the work of Kim and Kim (1985), who developed a multi-regional-multicommodity national transportation development model (Kim, T.J. and Kim, G.K, 1985).

The Kim and Kim Model (1985) minimizes the sum of costs for the production of commodities, transportation system cost of transporting the commodities via different competing systems (i.e., rail and highway) and the intermodal terminal handling cost of the commodities.

The transportation system component of the model also embeds in it the infrastructure costs (i.e., cost of expanding a system and cost of expanding an intermodal terminal).

While the Kim and Kim (1985) model was suited for the South Korean context during the mid 1980's there are several contextual differences that need to be accounted for in our North American case and the context of this dissertation. These include:

i) North America already has a well-established transportation system and the actors are not currently seeking to redevelop the system;

ii) The geographical scale of North America is many times larger than South Korea and thus the quantity and complexity of data is different;

iii) The freight rail infrastructure in North America is almost entirely privately owned whereas the South Korean infrastructure is government owned;

iv) The North American context includes international trade between Canada and the US compared to intranational trade within South Korea; and

v) The classic "first mile / last mile" problem is a larger issue in the North American logistics context than it was in the South Korean national development context.

The Kim and Kim (1985) model has been adapted to the Canadian and North America context for this study with a focus on the rail system only. The key differences between the original model and the adaptation used in this study are the removal of the commodity production variables and the addition of a new model component with variables representing drayage costs and market demand at regional economic centres in Ontario, Canada.

The model comprises of two stages:

(i) A doubly constrained gravity trip distribution model that determines the flows of commodities between terminals *i* and *j* using optimal transportation costs. The latter are based on optimization with route assignment in GIS to find the least cost route between terminals *i* and *j* for which the optimized cost becomes the fixed cost to transport goods between *i* and *j* in the second stage; and

(ii) A linear programming model that optimizes transportation costs, terminal handling costs and drayage costs to the Ontario Economic Regions.

The assumption is that firms will typically use the lowest cost alternative to get their goods from origin to destination. Intermodal terminals are the origin and destinations and other origins have been excluded from the model with the exception of regional economic centres in Ontario, Canada to minimize the amount of data required and complexity of implementing the model. It is noted that the origins and destinations must both be intermodal facilities. Unless otherwise noted all quantities are measured in US dollars or have been converted to equivalent US dollars as the standard unit of measurement in this dissertation. For the purpose of this analysis, the value of a commodity being hauled in a 53-foot container is calculated by measuring the weight of commodity that can be handled in a 53-foot container and multiplied by the cost of the commodity per weight. Commodity cost data was obtained from the US Bureau of Labor Statistics, Bureau of Economic Analysis and the US Census Bureau. A typical 53-foot container used in North America has a maximum cargo weight of 56,750 pounds (CIMC Intermodal, 2020). By multiplying the cost of commodity by weight and the maximum cargo weight the result is the value of commodity that can be transported in at 53-foot container. Using the total value of the commodity shipped cross-border in a month and dividing that by the value of commodity that can be shipped in a 53-foot container to estimate the number of 53-foot containers used to transport the commodity cross-border in a month. The linear optimization model used in this dissertation is as follows:

Minimize $$\sum_i \sum_j a_{ij} T_{ij} + \sum_i \sum_r d_i^r H_i^r + \sum_i \sum_k \sum_r y_{ik}^r G_{ik}^r$$

Equation 3.1 – Adapting the Kim and Kim Model (1985) to the North American Rail Context

The model is subject to the following constraints:

1. $E_i^r + I_i^r \leq H_i^r$ $\forall\, r$ and i
2. $\sum_r H_i^r \leq Q_i^r$ $\forall\, i$
3. $\sum_r X_{ij}^r \leq T_{ij}$ $\forall\ i$ and j
4. $\sum_k G_{ik}^r \leq EH_i^r + H_i^r$ $\forall\, r,\ i\ and\ k$
5. $\sum_i \sum_r G_{ik}^r = D_k$ $\forall\, r,\ i\ and\ k$

Where endogenous variables are:

E_i^r : amount of commodity r exported from terminal *i*;

I_i^r : amount of commodity r imported through terminal *i*;

G_{ik}^r: amount of commodity r drayed between intermodal terminal *i* and regional centre *k*.

EH_i^r : excessive amount of commodity *r* that cannot be handled with the existing capacity of terminal i. If this amount is greater than 0, this suggests the optimum expansion of terminal *i* for handling *r*;

H_i^r: amount of commodity *r* handled within the current capacity of terminal i. If the volume of commodity reaches Q_i^r, maximum terminal capacity, then a separate calculation will suggest optimum expansion of terminal *i* (EH_i^r) as described above;

T_{ij}: total amount of commodity transported between terminals *i* and j.

Exogenous variables and corresponding values are:

a_{ij} : transportation cost for shipping unit amount of commodity between terminals *i* and *j*. Unit user cost, $ / ton / mile ($ is US dollars). The cost data is available for each Class I railroad operating in the US from the STB;

D_k: market demand at regional economic centre *k*;

d_i^r : handling cost (user cost per unit amount of commodity *r* at terminal *i* (based on STB data);

e_i^r : annual equivalent construction cost for handling unit excess amount of commodity *r* at terminal *i* (based on STB data);

Q_i^r : handling capacity of commodity *r* at terminal *i* per month;

q : Number of tracks x trains per day x 240 containers per train x maximum 53’ container capacity of 28 tonnes x 365 days / month;

X_{ij}^{r} : amount of commodity *r* shipped from terminal *i* to terminal j (estimated using the doubly constrained gravity model;

y_{ik}^{r}: drayage cost between the terminal *i* and regional centre k.

The objective function is used to select the optimum (lowest cost) route and intermodal terminal by minimizing the sum of transportation costs, intermodal terminal costs and drayage costs. The important constraints used in this function are the operation and maintenance costs and the system component capacities. The constraint of time costs are captured as an output of the model where demand exceeds capacity for any of the components of the objective function. Expansion is modelled through the constraint variable EH_{i}^{r} and a calculation to identify required expansion by calculating EH_{i}^{r} by subtracting the intermodal terminal capacity Q_i from H_{i}^{r} in cases where $H_{i}^{r} > Q_i$. Modelling the expansion of the rail system though is beyond the scope of this dissertation.

The decision variables in this model are T_{ij}, H_{i}^{r}, and G_{ik}^{r}. These variables represent the current capacity of the transportation system, the intermodal terminals, and the amount of commodities drayed between intermodal terminals and regional centres. It is important to distinguish between the transportation system and the rail network. While related, the transportation system includes the capacity of vehicles used to transport the commodities, in this case the equivalent volume and weight capacity of a 53-foot intermodal shipping container whereas the rail network's capacity is measured in the number of trains carrying the equivalent of 250 intermodal containers per month. The primary purpose of using this model is to generate information for this research to determine the viability of adding intermodal1 terminals to a location on the rail system with an increased value of intermodal terminal capacity Q_i.

3.3 Model Interpretation

The model as implemented in this dissertation uses the transportation system component of the Kim and Kim (1985) model with a comprehensive rail network database, a much larger origin-destination matrix and the addition of variables y_{ik}^{r} and $G_{ik}^{r}$to include drayage costs and address the "first mile/last mile" problem:

$$minimize \sum_{ij} \left(a_{ij} T_{ij} \right)$$

Equation 3.2 – Adapted Transportation System Component of the Model

And an adapted portion of the port system component of the Kim and Kim (1985) model:

$$minimize \sum_{i} \sum_{r} \left(d_i^r H_i^r \right)$$

Equation 3.3 – Adapted Port System Component of the Model

With the addition of a component that calculates the drayage cost from intermodal terminals to regional centres:

$$minimize \sum_{i} \sum_{k} \sum_{r} y_{ik}^{r} G_{ik}^{r}$$

Equation 3.4 – New Drayage Cost Component of the Model

The transportation system, terminal system and drayage cost components are added together in this model to generate a minimum cost value to transport each commodity r using from each origin i to each destination j and then the minimum cost to dray each commodity *r* to regional centre *k*. Each of these components represent terms in the objective function of the linear optimization.

After the model is run there is one additional calculation that needs to be completed to determine if a location is feasible for a full-scale intermodal terminal. One of the outputs from the model is the H_i^r variable. By converting the amount of H_i^r to the equivalent number of 53-foot intermodal containers handled by the terminal per month and dividing by the number of days in the month to obtain the number of lifts per day *C*, the feasibility can be assessed. A full-scale intermodal terminal requires between 650 and 1,000 lifts per day to be feasible. If *C* is greater than or equal to the minimum requirement of 650 lifts per day, then a full-scale intermodal terminal could be feasible at a particular location on the rail network. If *C* is less than 650 lifts per day, then a full-scale intermodal terminal would not be feasible at a particular location on the rail network.

As discussed above the model requires a substantial amount of data. The following section includes descriptions and discussion about the data used in the model.

3.4 Data

The implementation of the cross-border rail flow model between Canada and the USA requires a very large quantity of data comprising several different sources and types. While some of the data exists in the public domain and could be adapted for use in the model, much of the data had to be generated. This section provides a description of the data and how it was created.

Publicly available railroad data sources in the North American context are very limited and thus it would be very desirable to create a methodology to aggregate and use data for research purposes. The current and historical North American rail network is available online (Center for Transportation Analysis, 2015). The North American rail network dataset was reduced so that only Class I railroad track segments located within Canada and the US remained. Additional columns of data were added to indicate track segments where intermodal terminals are located.

Commodity origin and destination flow data are available for trade between the North American Free Trade Agreement (NAFTA) / United States Mexico Canada Agreement (USMCA) countries at the province/state level measured in US dollar values (United States Department of Transportation Bureau of Transportation Statistics, 2018). As the commodity data is made available at the province/state level it needed to be allocated to each of the rail terminals in each jurisdiction and this was accomplished by assigning a weight to each facility and distributing the amount of commodity proportionally by the weight assigned to each terminal. This information was appended to the Class I rail network dataset for each segment containing an intermodal terminal.

Rail transportation cost data for the USA are available online as part of the Uniform Rail Costing System (United States Surface Transportation Board, 2019). Key measures used in this research for each Class I railroad are the cost per intermodal lift and total cost to move one ton of freight one mile. The cost per lift data was used in the linear optimization component of the model and the total cost to move one ton of freight one mile was applied and appended to the North American Class I rail network dataset for each segment of track. A description of how these data sources are used is included in a later section.

The public domain data was primarily obtained from Oak Ridge National Laboratories, the United States Department of Transportation – Bureau of Transportation Statistics and the

Surface Transportation Board's Uniform Rail Costing System. A summary of all data is included below.

The raw rail network data set (Oak Ridge National Laboratories Centre for Transportation and Analysis, 2015) is comprised of all current and historical segments of the rail network in North America including some attribute data that is not required for use in this research. The network is presented in details in the previous chapter.

The supply and demand data used in this model is publicly available from the (United States Department of Transportation, 2018) and was obtained for the month of June 2017 in a spreadsheet compatible format. The data is comprised of the dollar value (US Dollars) of commodities shipped by rail between Canada and the US and the US and Canada for cross-border goods movement only. Separate queries were prepared for each of the 99 individual commodity group for each direction of cross-border transport and were aggregated into the following commodity groups:

Table 3.1 – Aggregated Commodity Groups used in the model (Source: US DOT BTS, 2017)

Commodity Groups	**Description**
01-05	Animal & Animal Products
06-15	Vegetable Products
16-24	Foodstuffs
25-27	Mineral Products
28-38	Chemicals & Allied Industries
39-40	Plastics / Rubbers

41-43	Raw Hides, Skins, Leather & Furs
44-49	Wood & Wood Products
50-63	Textiles
64-67	Footwear / Headgear
68-71	Stone / Glass
72-83	Metals
84-85	Machinery / Electrical
86-89	Transportation Equipment
90-97	Miscellaneous
98-99	Service

The supply O_i^r and demand D_j^r data were used to estimate the flows X_{ij}^r values used in constrained 3 of the linear optimization model presented in the previous section. X_{ij}^r is modeled using the doubly constrained gravity model formulation:

$$X_{ij}^r = A_i^r O_i^r B_j^r D_j^r \exp{(\beta^r t_{ij})}$$

where A_i^r and B_j^r are balancing terms and β^r is friction of space parameter associated with shipping commodities r from terminals *i* to terminals *j*. The Hyman algorithm is used to estimate the parameters β^r for each commodity group, eliminating the need for a maximum likelihood analysis. While the Hyman algorithm was successful in obtaining β^r parameters for the following commodity groups r = 44-49, 72-83 and 98-99, its application to the remaining groups was not successful. More specifically, the estimated β^r parameters were counter intuitive in term of their sign (i.e. positive) due to the sparse nature of the observed data for these groups. To obtain a sensible β^r, the unconstrainted gravity model using an unconstrained order of least squares algorithm was applied to the flows comprising all the commodity groups except for the following 3 (r = 44-49, 72-83 and 98-99). The gravity model is run iteratively until the value for β^r does not change between iterations. The unconstrained gravity model used is as follows:

$$X_{ij} = k\, O_i^{\lambda}\, D_j^{\alpha} \exp\left(\beta^r t_{ij}\right)$$

The final set of β^r parameters used to calculate X_{ij}^r are as follows:

Table 3.2 – Estimated β^r parameters used to estimate X_{ij}^r flows

Commodity Groups	β^r
44-49	-0.0000041331
72-83	-0.0045380868
98-99	-0.0000632211
Other 13 groups	-0.0002083755

It is noted that X_{ij}^r is used as a variable in the gravity model and also used as a constraint in the Linear Programming Formulation discussed later in this Chapter. The use of X_{ij}^r as a variable in the gravity model and as a constraint in the Linear Programming Formulation is acceptable because the value of the commodity flows between intermodal terminals estimated by the gravity model must be less than or equal to the transported between intermodal terminals.

The cost data used in this model is from the Uniform Rail Costing System for the year 2017 and is applicable for the month of June 2017 which is analyzed in this dissertation and obtained in a spreadsheet format from the United States Department of Transportation Surface Transportation Board. The Uniform Rail Costing System data includes a comprehensive summary of costs for each of the Class I railroads operating in the US and an aggregated summary for railroads operating in the eastern and western US.

It is acknowledged that all rail traffic on Class I Railroads in Canada and the USA contains both domestic and international commodity flows. At least 42% of rail traffic in the USA originates or terminates at an international location (American Association of Railroads, 2020). For Part II, as the model data set uses only international commodity flows, the issue of domestic flows impacting the model's results was tested by adding Freight Analysis Framework 4 (Centre for Transportation Analysis, Oak Ridge National Laboratories, 2018) data from 2017 for US domestic origin and destination pairs to test for capacity issues. The following assumptions were made to use the FAF4 data to represent domestic commodity flows:

1. Average of value per 53-foot container equivalent for all commodity groups is used;
2. Proportion of commodities shipped internationally is the same as commodities shipped domestically;
3. Proportion of commodities shipped domestically in Canada is the same as the proportion of commodities shipped domestically in the USA.

Domestic commodity flows were represented by adding the value of domestic shipments weighted proportionately by each terminal in each state/province to the value of international shipments for each terminal in each state/province. A sensitivity analysis was performed by increasing the amount of domestic commodity flows by up to 10% over actual to determine if system capacity is an issue. At a 10% increase in domestic commodity flows system capacity is identified as an issue.

The databases used in this model was built using the Oak Ridge National Laboratories rail network shapefile as its foundation. The rationale for using the shapefile as the foundation is that a shapefile is comprised of multiple files including a DBase IV (.dbf) database that can be exported/imported to/from a variety of file formats including several common text files and formats compatible various spreadsheet programs. This will be further discussed in the following “Implementation” section that goes into detail about the methodology used to perform the GIS-based network analysis with route selection and the linear programming model used to implement the model.

It is noted that the database has been designed to allow for future rail network analysis on a trip basis by assigning what turnouts may be permitted at existing junctions based on existing track layouts – i.e. a train cannot turn at a diamond crossing or a train could take the straight-through or diverging route at a turnout. Originally a more-micro-level route selection approach was considered though after some exploration a macro-level route selection approach is preferred in consideration of the geographic scale and time limitations on the preparation of this research. A summary of the variables used in the model is included in Appendix ‘A’.

As part of the preparation of the GIS shapefiles for use in the Network Analysis, the following variables were calculated for intermodal terminals using scripts in ArcGIS:

E_i^r: USD value / cost per 1,000 lbs / 1,000 x proportion of provincial or state USD amount assigned to the intermodal terminal.

I_i^r: USD value / cost per 1,000 lbs / 1,000 x proportion of provincial or state USD amount assigned to the intermodal terminal.

d_{ij}: Distance from intermodal terminal to regional centre without rail x \$1.69 USD per mile.

Q_i^r: Acres / 400 acre intermodal facility (with 1,000 container per day capacity) x 1,000 lbs/ton x 365 days / 12 months.

q: Number of tracks x trains per day x 240 containers per train x maximum 53' container capacity of 28 tonnes x 365 days / month.

The following figures below are shown to characterize the nature of the data used in this research:

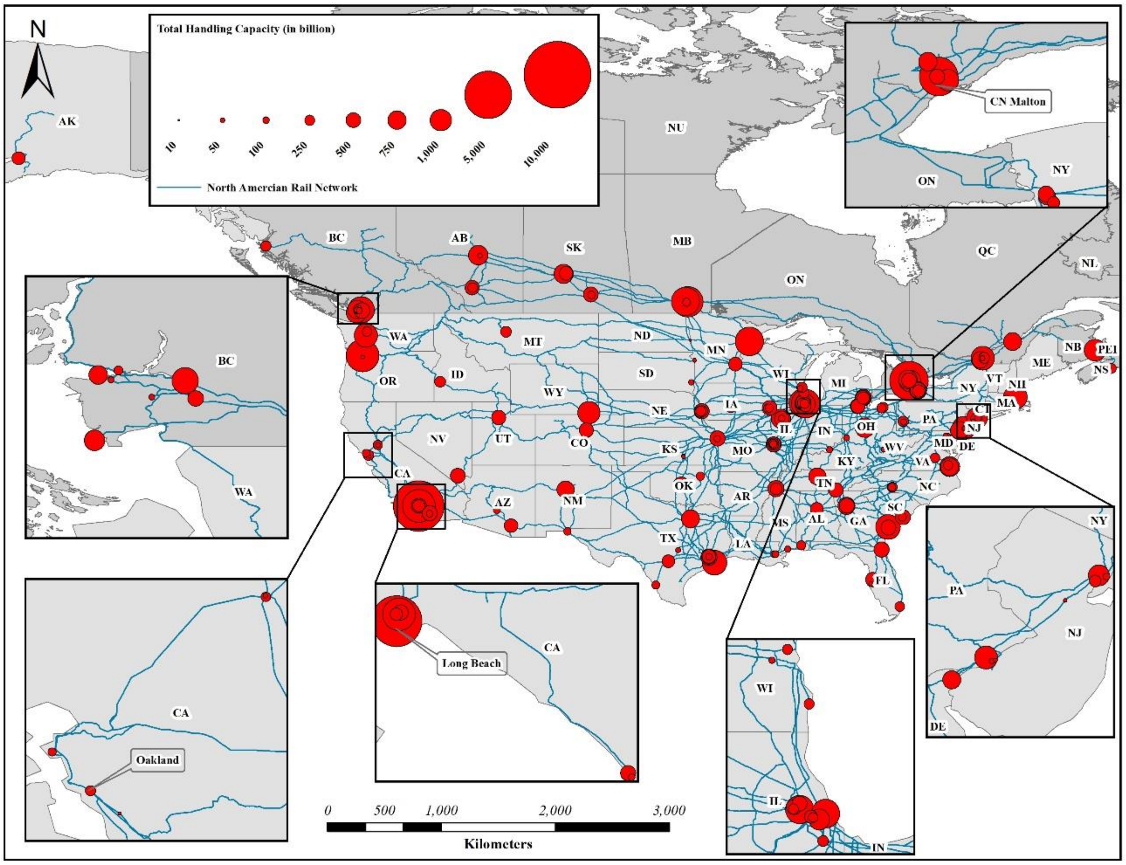

Figure 3.1 – Spatial Distribution of Rail Intermodal Terminals with Handling Capacity in Billions of US Dollars The largest intermodal terminal handling capacities are located at places on the Class I rail network where there are major sea ports such as along the west

coast of North America and at major centres close to areas with large quantities of consumption such as in the US Midwest, east coast and in the Greater Toronto Hamilton Area of Ontario. Mid-sized intermodal terminals exist elsewhere throughout the Class I rail network. It is noted that in some areas where multiple intermodal terminals exist, there may be size limitations due to key factors such as vacant land or price of land.

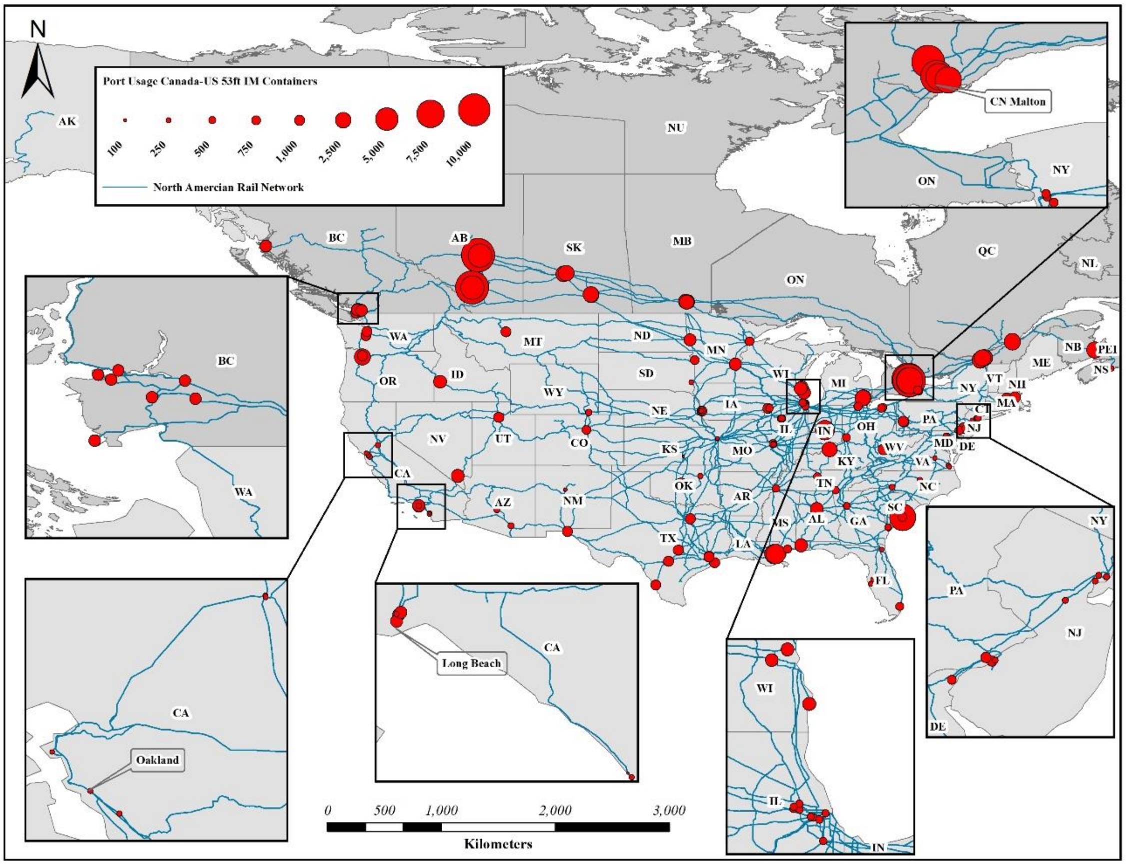

Figure 3.2 – Spatial Distribution of Rail Intermodal Terminals with Canada-US Usage

The capacity of intermodal terminals in terms of Canada-US cross-border trade varies with location indicating that terminals in Ontario and Alberta Canada play a greater role in the cross-border rail traffic than other terminals in Canada. In the US there are more intermodal terminals however the spatial distribution of cross-border intermodal rail flows appears more dispersed than in Canada.

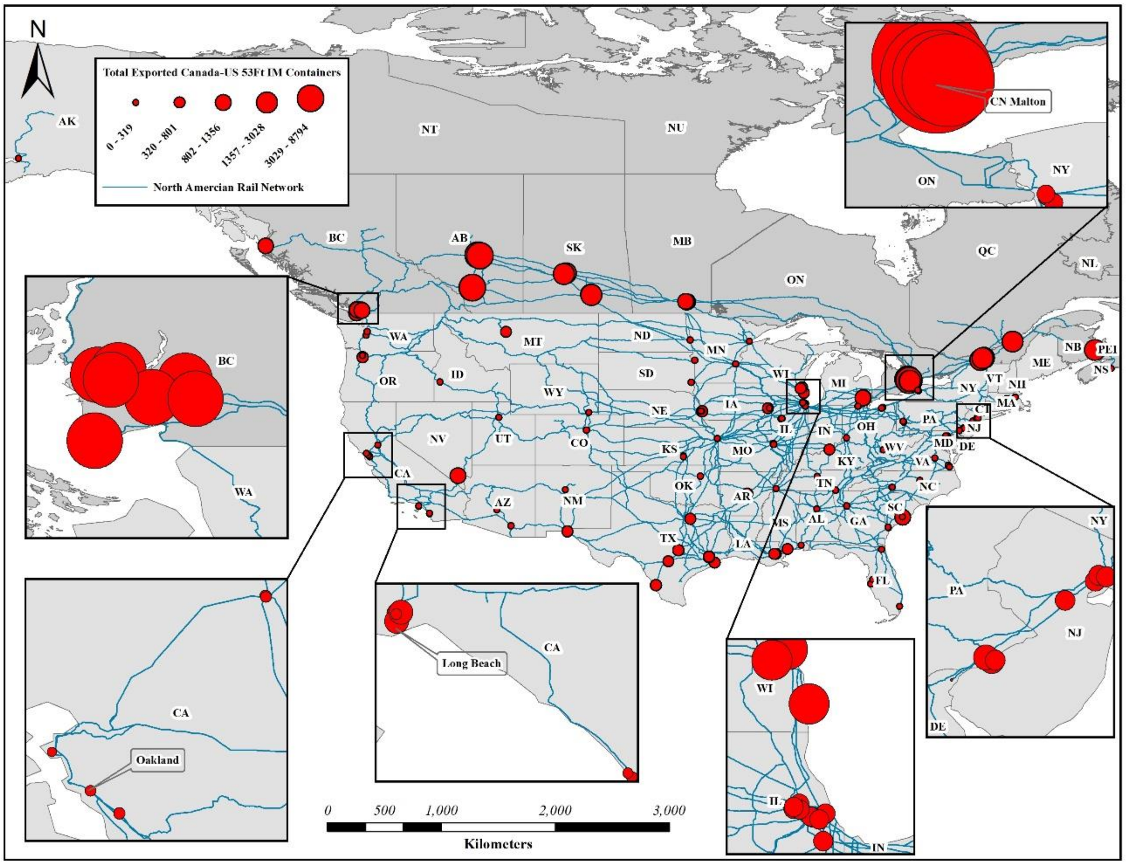

Figure 3.3 – Spatial Distribution of Rail Intermodal Terminals with Exports

The pattern of rail intermodal exports from either Canada or the US shows that more commodities exported by intermodal rail are more concentrated from the intermodal terminals in British Columbia, Alberta, Saskatchewan, Manitoba, Ontario and Quebec Canada compared to exports from the US. Rail intermodal exports from the US to Canada are more dispersed with larger quantities being shipped from the Chicago, Illinois area, Detroit Michigan and the intermodal terminals near the Gulf of Mexico.

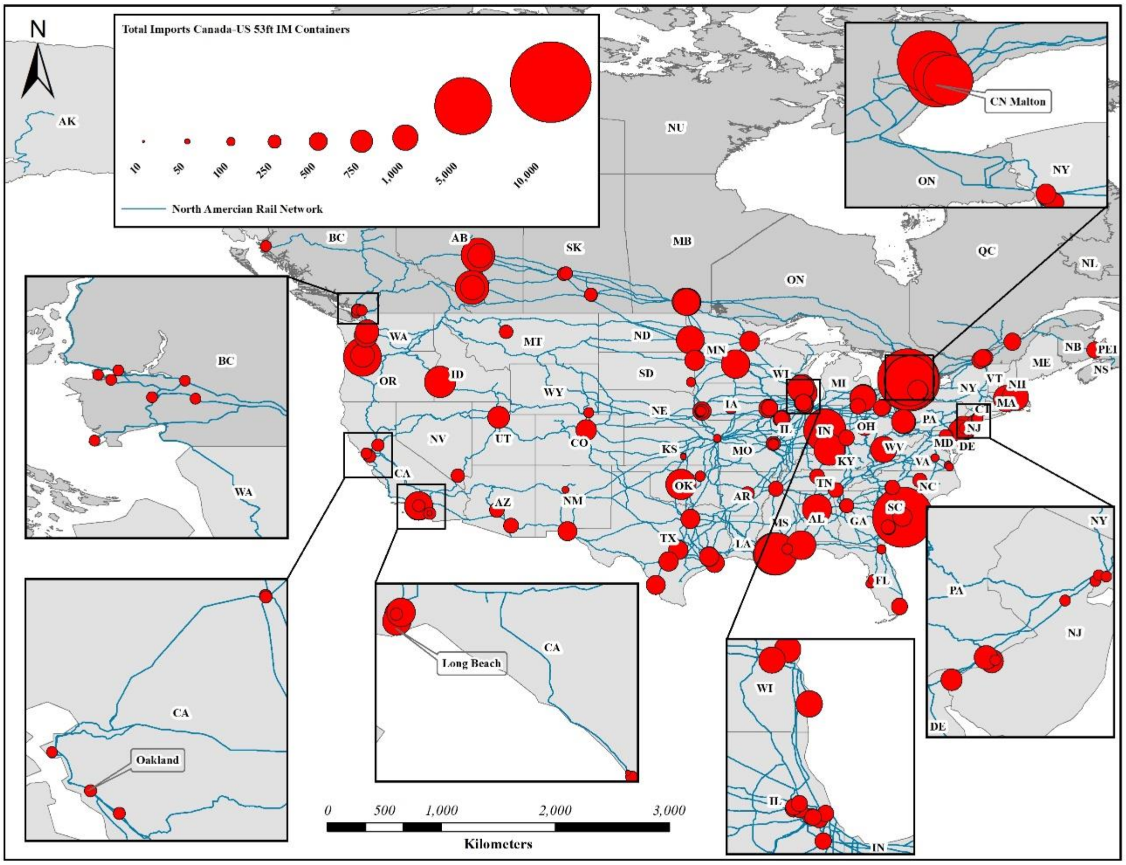

Figure 3.4 – Spatial Distribution of Rail Intermodal Terminals with Imports

The observation of rail intermodal imports shown in Figure 3.4 differs compared to the exports shown in Figure 3.3 whereas the US intermodal terminals receive more imports from Canadian terminals as indicated by the greater prevalence of larger circles in Figure 3.4. Most of the Canadian imports are received at intermodal terminals in the Greater Toronto Hamilton Area of Ontario and in the two large centres of Calgary and Edmonton Alberta.

3.5 Implementation

There are two key technological changes that have occurred since the early 1980’s when the Kim and Kim (1985) model was developed, firstly desktop computing power has exponentially increased in the first quarter of the 21st century relative to the state-of-the-art computing power that was available to researchers in the early 1980's. Secondly, commercial-off-the-shelf vector-based geographic information system software with a vast selection of add-ons, development tools and base mapping are now widely available. These technological changes informed the implementation of the model.

The implementation of the model is comprised of two parts:

Part I – GIS Network Analysis

Part II –Linear Programming Analysis

- i) Transportation Problem
    - a. Minimizing the system costs
- ii) Linear Programming Formulation
    - a. Satisfying known flows using existing system capacity constraints

Part I involves the uni-modal search using the Network Analyst Extension of ArcGIS 10.7.1 to determine the optimal route between origin-destination pairs based on an existing hierarchy of relationships between the Class I railroads and lowest cost. Network Analyst uses the Dijkstra Algorithm (Dijkstra, 1959) to estimate the shortest path between pairs of nodes in a network. Recent research has used the Dijkstra Algorithm to evaluate scheduling and routing algorithms for rail freight in Poland (Bozejko et al., 2017), evaluation of constraint-based routing models for the transport of radioactive materials in USA (Peterson, undated) and a railway travel-time optimization system in Nigeria (Otuneme et al., 2018). In the Poland, USA and Nigerian examples, the network used included government-controlled routes or routing options. The recent research does not reflect the actual situation in the North American freight rail transportation systems which is privately owned and operated and access is controlled by the firms that operate their own networks.

To compensate for the ownership structure of the North American rail network, a hierarchy of relationships is necessary to include so that routing of shipments closer reflect how the railroads actually route the movement of goods from terminal to terminal. If a hierarchy of railroads is not used, the model will treat the rail network similar to that of the interstate highway system where routing is typically that of lowest cost. Table 3.3 represents the author's estimation of the hierarchical relationship between the Class I railroads. These estimates are based on the author's following of railroad industry publications and news over the past 30-plus years that has resulted in a sound understanding of the railroad industry and the relationships between the Class I railroads. A lower number indicates that the network analysis will use a segment of the rail network owned or with trackage rights over another intersecting segment with a higher number. The hierarchy in the model can be changed for future model runs in the event that relationships between the Class I railroads change due to future circumstances such as mergers and acquisitions or restructuring of corporate assets such as a scenario that occurred with the former Conrail being divided with assets going to CSXT, NS and a new Conrail Shared Assets corporation.

Table 3.3 – Network Analysis Railroad Hierarchy

Railroad	**BNSF**	**CN**	**CP**	**CSXT**	**KCS**	**NS**	**UP**
BNSF	1	2	5	2	4	4	7
CN	2	1	6	3	2	5	4
CP	5	6	1	5	5	3	2
CSXT	3	4	4	1	7	7	6
KCS	6	3	7	6	1	6	5
NS	7	7	3	7	6	1	3
UP	4	5	2	4	3	2	1

Additionally, an overall operating cost ranking exists among the Class I railroads as shown in Table 3.4.

Table 3.4 – Cost Ranking. Data source – 2017 Uniform Rail Costing System

Ranking	**Cost per Ton per Mile**	**Railroad**
1	$0.002014	UP
2	$0.002288	BNSF
3	$0.00242	CP
4	$0.002532	CN
5	$0.002582	KCS
6	$0.00288	NS
7	$0.002901	CSXT

For the purpose of the network analysis it is assumed that railroads with lower operating costs will pass savings on to customers by charging lower fees. This may not necessarily be the case in the real world as shipping rates are frequently negotiated between the railroads and their customers.

For each of the commodity groups identified in Table 3.1, a new network dataset including the attribute data for each of the approximately 12,900 rail network segments is created to model the flows between Canada and the US in each direction and for each of the 7 Class I railroads. This works out to be 224 network datasets (16 commodities in each direction x 7 Class I railroads) per scenario being modeled. The creation of network datasets provides the opportunity to identify which variables will be modeled in the network analysis, the hierarchy between Class I railroad route segments and the specification of any attributes applied to the variables such as cost and distance. The following network diagram provides an overview of the model (see Figure 3.5 below):

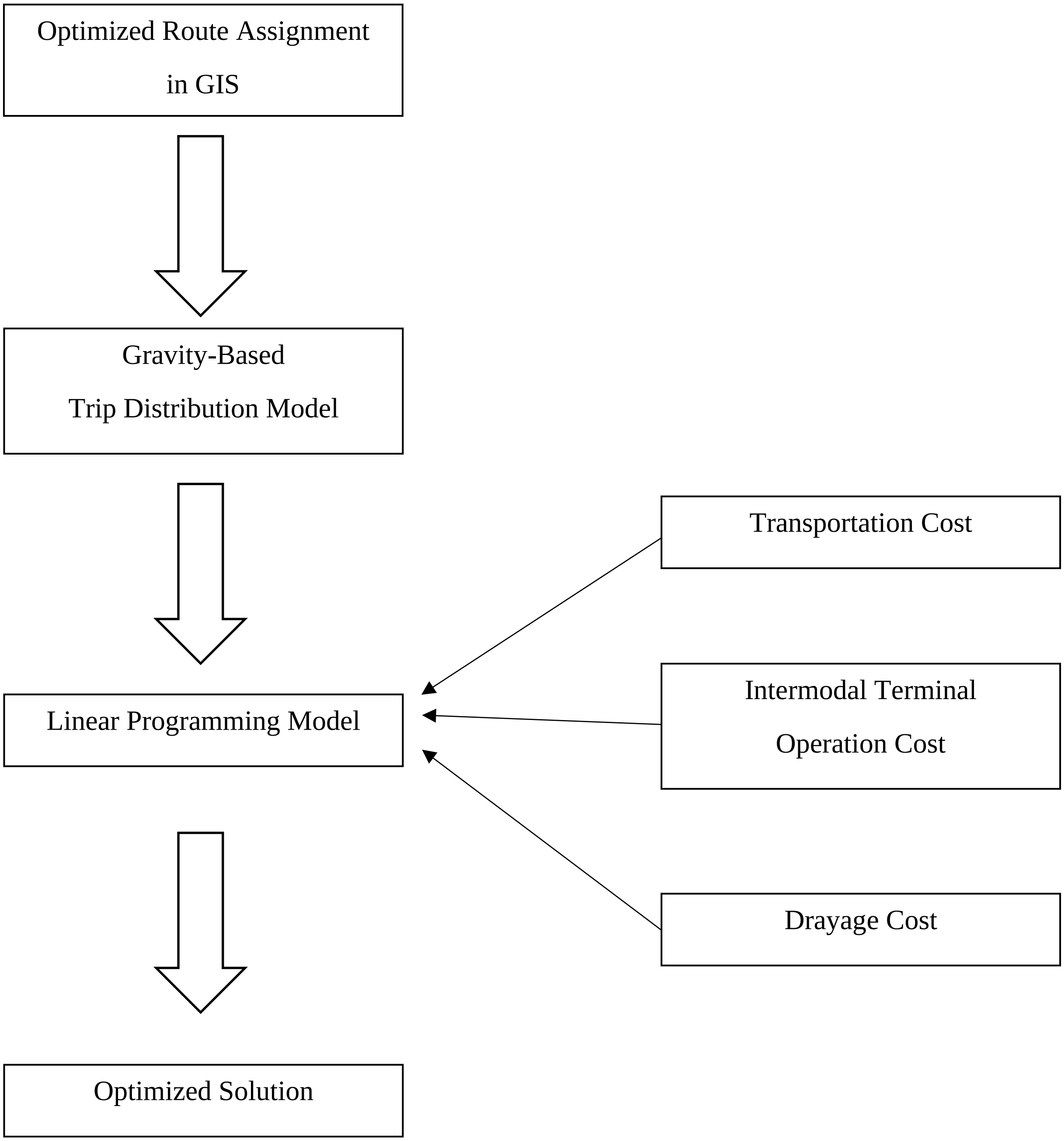

Figure 3.5 – Model Network Diagram

The network datasets are used in a network analysis to produce a set of origin-destination cost matrices between each origin-destination pair for each variable that will be used in Part II. Each of the 224 network analyses performed required approximately 45 minutes of running time on an Intel i7-8700 CPU base speed of 3.20 GHz operating overclocked at

4.28 GHz, 6 cores plus 6 virtual cores and 64 GB of RAM. Each run of the network analysis produced an output matrix for a total of 224 matrices for each scenario modeled.

The result of the network analyses is a table that identifies the lowest rail shipping cost option route option between each origin and destination pair. In order for use in Part II, the output from Part I requires conversion from a DBase IV file to an Excel spreadsheet format so that a pivot table containing a 180 × 180 matrix can be copied into a template for the linear optimization.

Part II is a linear optimization run in Open Solver (Mason, 2011) that calculates the demand for individual routes between two terminals using the three decision variables discussed above and is performed in a spreadsheet environment with linear optimization tools. The linear optimization model is setup into a spreadsheet that is 3,436 rows by 920 columns in size. It is not practical to include a graphic of the spreadsheet due to the physical size that it takes up on a computer monitor. The spreadsheet is organized into sections for cost variables, commodity flows, constraints, decision variables and the solution. Data for the cost variables, commodity flows and constraints were manually copied from the Part I output files and the aforementioned Hyman Algorithm (Ortúzar and Willumsen, 2011) doubly-constrained gravity model spreadsheets into the corresponding sections of the linear optimization spreadsheet. To execute the linear optimization model, the Open Solver add-in (Mason, 2011, University of Auckland, New Zealand, 2017) was added to the spreadsheet and programmed with the locations of the variables, constraints and solution cells. Solving the model required approximately 20 minutes of running time on an Intel i7-8700 CPU base speed of 3.20 GHz operating overclocked at 4.28 GHz with 6 cores plus 6 virtual cores and 64 GB of RAM.

The output from Part I of the Model generated in ArcGIS Network Analyst shown in the form of route maps (see Figure 3.6 and Figure 3.7) and an output table (see Figure 3.8) that will be used in Part II of the Model.

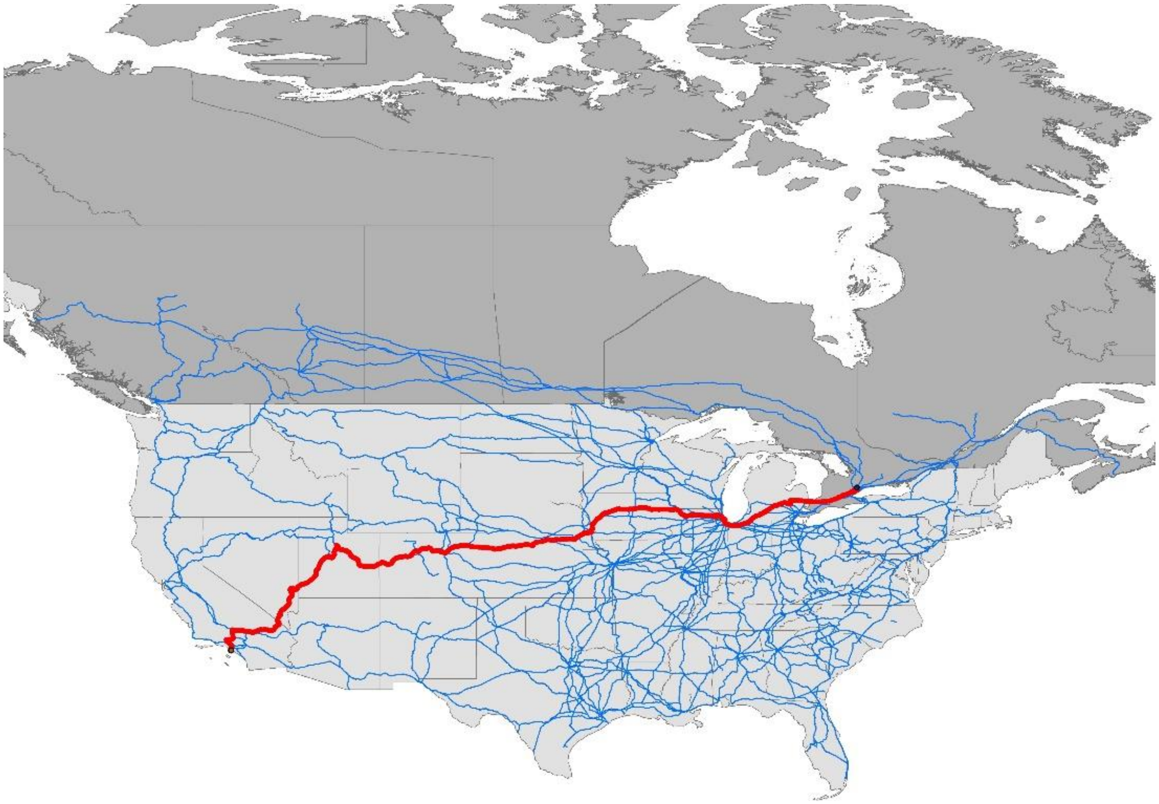

Figure 3.6 – Sample Output Map for Estimated Long Beach to Toronto Route

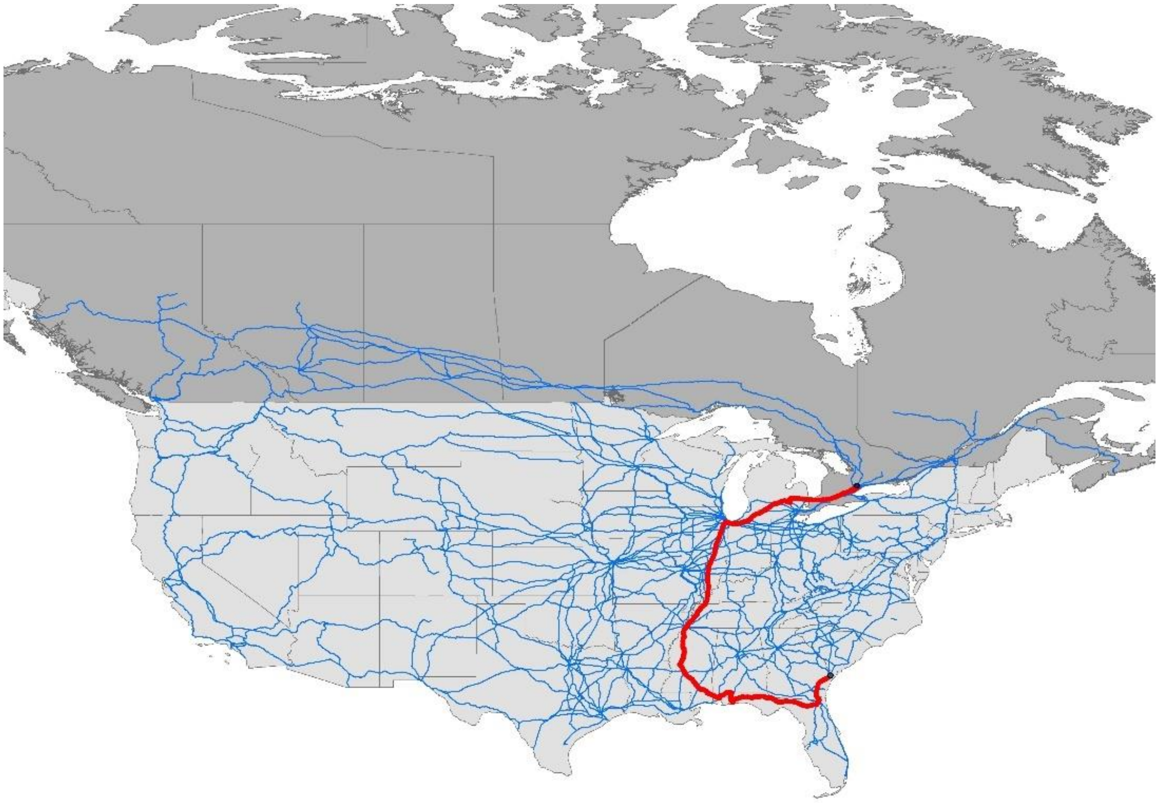

Figure 3.7 – Sample Output Map for Estimated Savannah to Toronto Route

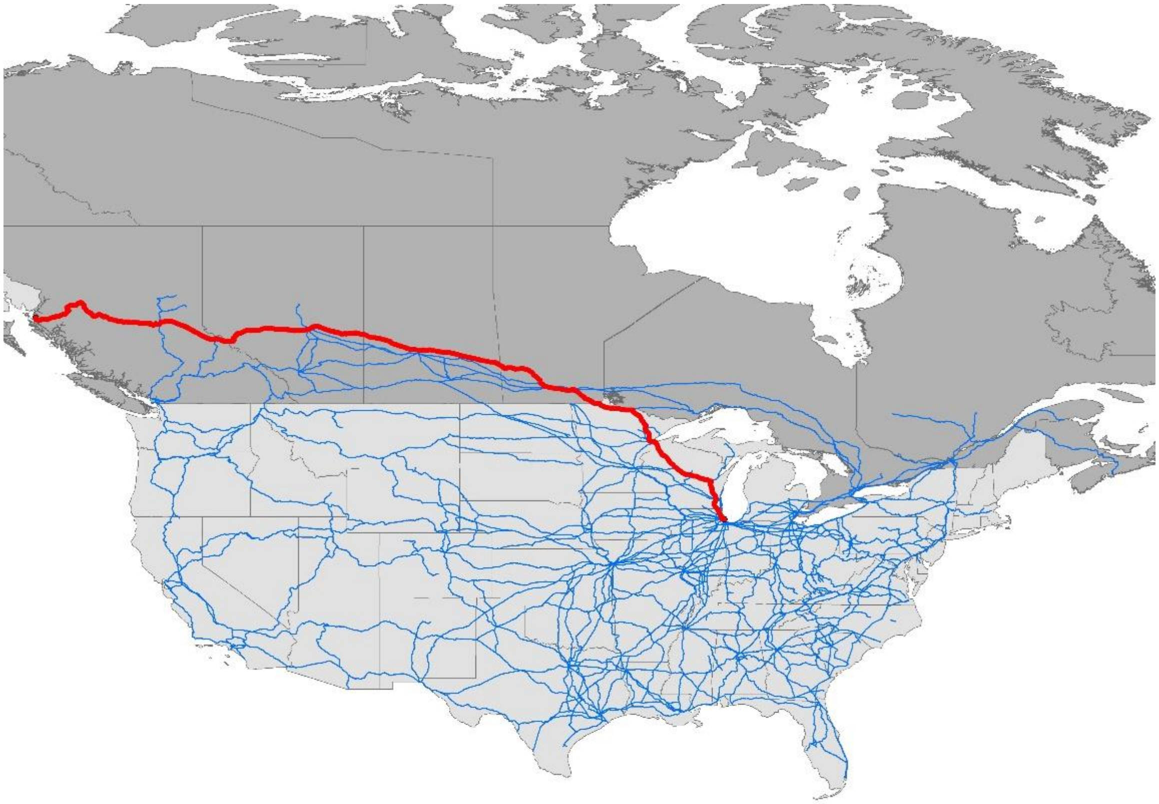

Figure 3.8 – Sample Output Map for Estimated Prince Rupert to Chicago Route

The output tables generated by Network Analyst (see Appendix ‘B’) contain cost and distance data calculated for each Class I railroad and are processed in a spreadsheet to be used as part of the input data for Part II, the Open Solver Linear Optimization component of the Model. The output of the Open Solver Linear Optimization component is in the form of tables and can be presented in a graphical representation. Tables 3.5 and 3.6 and Figure 3.9 show the results of the “Baseline Scenario”.

Table 3.5 – Objective Function Result for the Baseline Scenario

Transportation Costs	Terminal Operating Costs	Ontario Drayage Costs	Total Optimized Cost
$ 8,965,262.64 (30%)	$ 15,841,479.00 (54%)	$ 4,667,285.35 (16%)	$ 29,474,026.99 (100%)

Table 3.6 – Number of 53-foot Equivalent Intermodal Containers Between Canada and the USA Drayed Between Existing Ontario Intermodal Terminals in the Greater Toronto Hamilton Area and Ontario Economic Regions

Location	CN Brampton	CN Malton	CN Mississauga	CP Vaughan	Total
Chatham-Kent	0	0	0	276	276
Toronto	5,865	0	10,321	1,189	17,375
Hamilton-Niagara Peninsula	0	0	0	2,116	2116
London	0	0	0	1,774	1,774
KWCG	0	0	0	1,449	1,449
Brockville	0	272	0	0	272
Ottawa	0	3,264	0	0	3,264
Kingston-Pembroke	0	1,237	0	0	1,237
Niagara	0	0	0	1,213	1,213
Muskoka-Kawarthas	0	1,023	0	0	1,023
Sarnia	0	0	0	343	343
NorthEast	395	1,090	0	0	1,485
Windsor	0	0	0	1,080	1,080
Stratford-Bruce Peninsula	0	0	0	807	807
NorthWest	627	0	0	0	627
Total	6,887	6,887	10,321	10,247	34,342

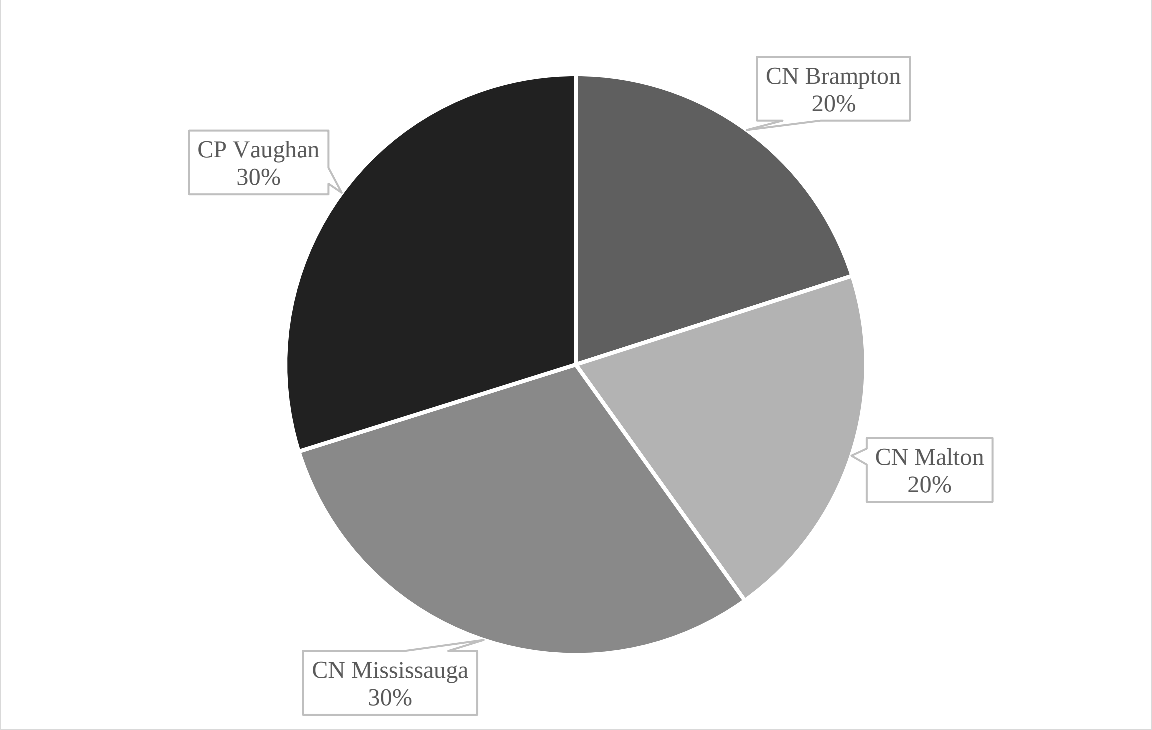

Figure 3.9 – Estimated Baseline Share – Canada-US Commodities Shipped by Rail to the Existing Ontario Intermodal Terminals in the Greater Toronto Hamilton Area

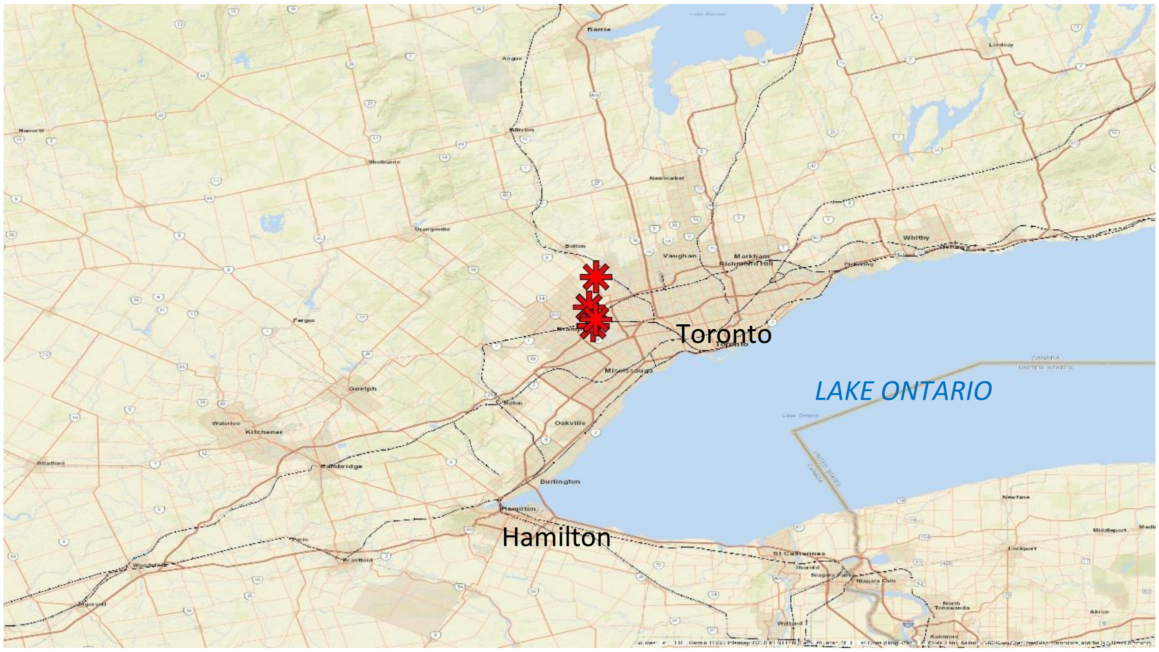

Figure 3.10 – Greater Toronto Hamilton Area Intermodal Terminals

The results in Table 3.5 for the Objective Function are shown in four terms: Transportation Costs, Terminal Operation Costs, Drayage Costs and the Total Optimized Costs. These amounts represent the optimized costs incurred for cross-border rail between Canada and the US for the month of June 2017. An optimized operating cost of approximately \$29.5 million USD to move over 34,000 containers or approximately \$860 per container (on average). Limited data on North American rail costing for shipping an intermodal container is available as these are typically negotiated on a contract, project or spot price basis by the railroads or logistics firms. The estimated cost per intermodal carload (Transport Canada, 2007) for shipments on a variety of Canadian intermodal routes ranged from \$541 to \$5,372 for a relatively short 25-car intermodal train. It is also noted at the time of the (Transport Canada, 2007) study that double-stack intermodal container cars were not widely used in Canada. The \$860 per container figure seems reasonable considering inflation since the time of the Transport Canada study, longer train lengths and more fuel efficient locomotives the actual rates the Class I Railroads are higher including any applicable taxes and insurance fees. This translates into an average of \$258 (i.e.30%) for terminal-to-terminal transportation cost by rail, \$464 (i.e., 54%) for terminal operation costs, and \$138 (i.e., 16%) for drayage cost.

The results for the “Baseline Scenario” were generated on an Intel i7-8700 CPU base speed of 3.20 GHz operating overclocked at 4.28 GHz with 6 cores plus 6 virtual cores and 64 GB of RAM. The total run time for Part I was approximately 10,080 minutes and the total run time for Part II was approximately 20 minutes. The subsequent chapters discuss modifying the “Baseline Scenario” to develop and implement further scenarios.

This chapter provided an introduction to modelling rail networks, a discussion about historical models that led to the inspiration for the model, formulation of the model, data required and implementation of the model. A Baseline Scenario was created to test the model in the ArcGIS Network Analyst and Open Solver Linear Optimization environments. The results produced are deemed to be satisfactory and provide a foundation for additional analyses. The Baseline Scenario is modified in the following chapters to examine if sufficient lifts would be obtained if a full-scale intermodal terminal was developed in Windsor-Essex and examining the impacts on existing full-scale intermodal terminals in Ontario if a small-scale intermodal technology is introduced.

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CHAPTER 4

FULL-SCALE INTERMODAL TERMINALS

4.1 Introduction

This Chapter includes a discussion of how the model described in Chapter 3 is implemented with a description of the “Baseline Scenario”, followed by implementation and discussion about using the model to test the “Full-Scale Intermodal Scenario” in the context of the economic geography of Windsor-Essex.

Located in southwestern Ontario adjacent to the manufacturing heartland of the United States, Windsor-Essex has four international border crossing points with a fifth crossing coming in the early 2020’s including 2 road crossings: the Ambassador Bridge, the Windsor-Detroit Tunnel, a truck ferry, an international rail tunnel and the Gordie Howe International Bridge that is under construction at the time of writing. Excluded from these border crossings are international airports in Windsor and the metropolitan Detroit area. A satellite image of Windsor-Essex is shown in Figure 4.1

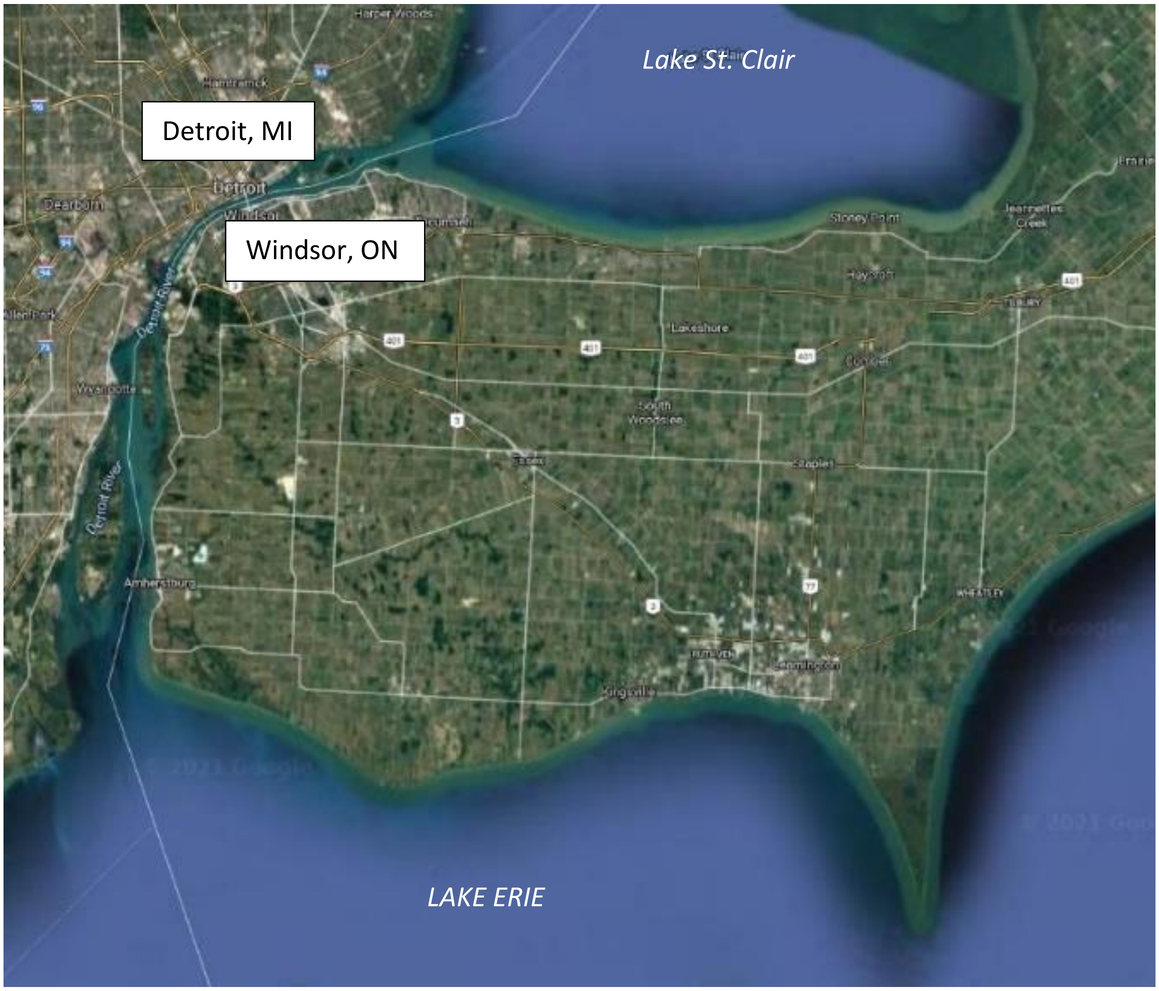


Figure 4.1 – Satellite Image of Windsor-Essex, Source: Google/Terra Metrics, 2021

Windsor-Essex is in a unique situation of being located on the Canada-US border and having thriving manufacturing, agricultural and transportation equipment sectors with cross-border supply chains. This means that every time commodities are moved across the border that they are subject to the customs and security functions of the Canadian or American border rules and regulations (Anderson, 2012). This is an existential challenge that most economic regions do not face. Additionally, the border crossings in Windsor-Essex are the busiest between Canada and the US by number of crossing trips, volume and value (US DOT BTS, 2018).

The border crossings at Windsor, Ontario and Detroit, Michigan serve both local and distant suppliers and consumers including major North American centres in Ontario, Quebec, Michigan, California, Texas, Ohio and New York. Products that cross the border to or from Ontario are consumed or produced in 15 economic regions shown in Table 4.1 and geographically in Figure 4.2.

Table 4.1 – Populations of Ontario Economic Regions (Source: Adapted from Statistics Canada, 2016 Canada Census)

Economic Region	**Population (adapted from the 2016 Canada Census)**
Windsor	398,953
Chatham	102,042
Sarnia	126,638
London	655,366
Kitchener-Waterloo-Cambridge-Guelph	757,880
Stratford	298,070
Hamilton-Niagara Peninsula	781,512
Niagara	447,888
Toronto	6,417,516
Muskoka-Kawarthas	377,918
Kingston-Pembroke	456,937
Brockville	100,546
Ottawa	1,205,703
North East	548,449
North West	231,691

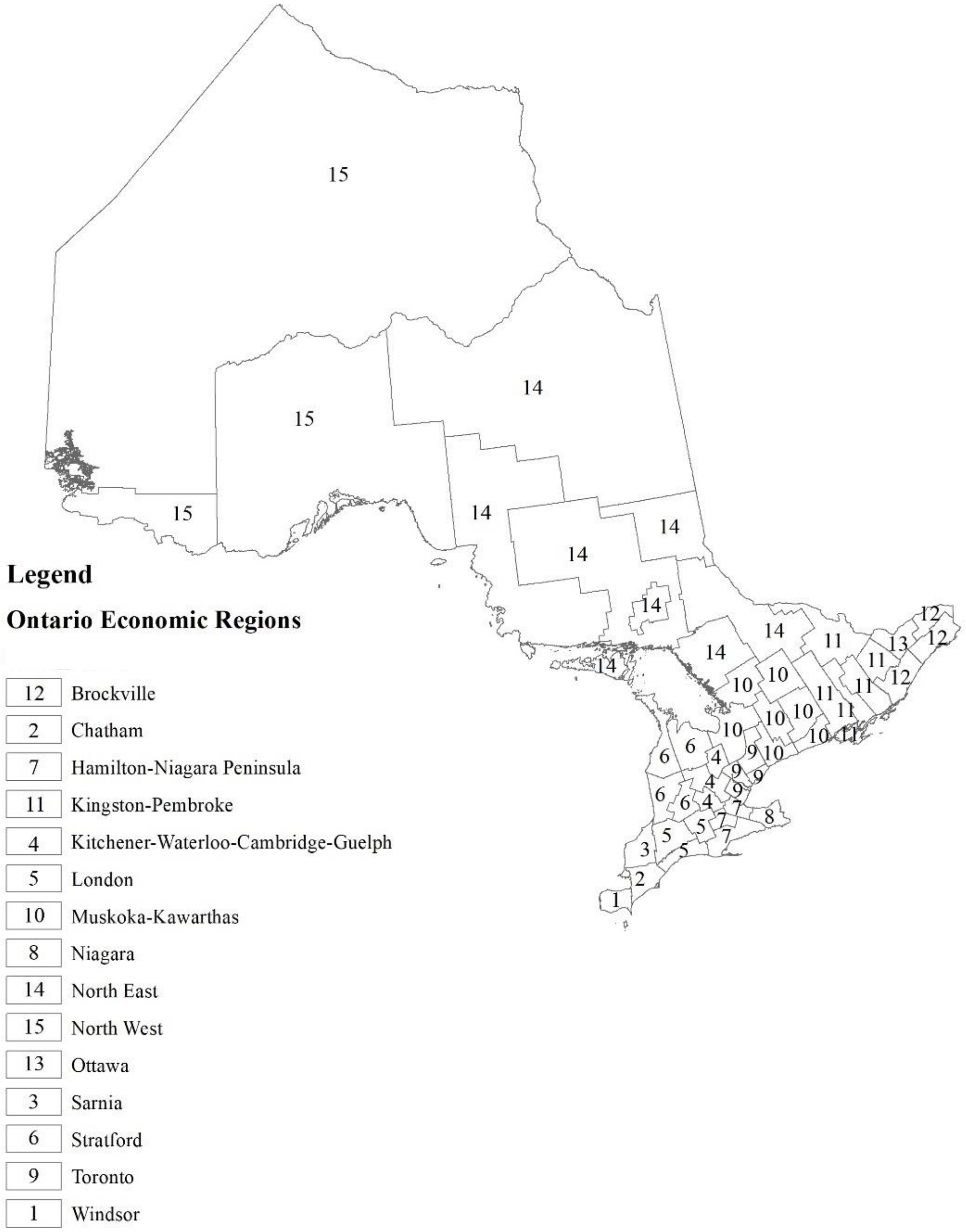


Figure 4.2 – Ontario Economic Regions

The rail network in Windsor-Essex includes the CP mainline connecting Toronto with Chicago, a CN/VIA Rail line connecting Windsor and Detroit with London, Ontario, and a recently abandoned CN line known as the Canada Southern corridor that was formerly owned by the New York Central and then successor Conrail. Prior to abandonment the Canada Southern corridor was the shortest distance rail route between Detroit, MI and Buffalo, NY as the other US routes travelled around the south shore of Lake Erie which resulted in approximately 4 hours of additional travel time. All rail corridors in Windsor-Essex connect to US by the CP-owned former New York Central rail tunnel that runs under the Detroit River between Windsor and Detroit.

While there is well established research base on topics related to industrial site selection, there is little published research on where to locate logistics facilities such as intermodal terminals in the context of commodity flows on rail networks and even less in the context of cross-border commodity flows or the North American context. Research that exists on modelling rail flows is largely focused on passenger transport and predominately in the European and Asian contexts.

There is a wealth of recent research from Europe (Anand et al., 2015; Eng-Larsson and Kohn, 2012; Kordnejad, 2012; Kordnejad, 2014; Monios, 2015; Sarrka, 2011; and Woodburn 2003) on topics related to rail and truck/sea intermodal, supply chain management involving rail transportation, terminals serviced by rail, and modelling of rail or intermodal transportation networks (Assad, 1980; Fernandez et.al, 2004; Ham et. Al, 2005a; Ham et al., 2005b; Kim and Kim, 1985; Kim, 1986; Yan et al. 1995; and You and Kim, 1999). A literature search identified that there is some research in the US context (Ham et al. 2005a; Ham et al., 2005b; Kim et al., 2002; Lee, 2015 and Uddin, 2019). Topics related to the North American cross-border flow of commodities by rail or intermodal are few including Anderson and Coates, 2010; Anderson, 2012; Anderson and Brown, 2012; Aspila and Maoh, 2014 and Park et al., 2014.

There are reasons for this including the complexity of modelling freight transportation and the limited availability of rail freight data, particularly in the North American context where the actors are primarily private firms and the rail networks are almost exclusively owned by private railroads who are not obligated to release information about their operations except where required by law. One area that information about rail freight commodity flows is available in the North American context is cross-border trade between the three countries who participate in the North American Free Trade Agreement (NAFTA) / United States – Mexico – Canada Agreement (USMCA). As part of the tripartite agreements trade information between the three countries is published for 99 commodity groups for all modes of transportation and for each border crossing. This chapter begins to address the knowledge gap that exists in the research base.

4.2 Model Specification

A linear programming approach has been taken to model cross-border rail between Canada and the USA. This approach focuses on minimizing operating costs, construction costs and handling costs to optimize performance of the system. The inspiration for this model comes from the work of Tschango John Kim and Jong Gie Kim's Macroeconomic and Network Generation Model, a multi-regional-multicommodity national transportation development model (Kim, T.J. and Kim, G.K, 1985). The model used in this analysis is shown in Equation 4.1. A detailed description of the model is provided in Chapter 3.

$$\text{Minimize} \qquad \sum_i \sum_j (a_{ij} T_{ij}) + \sum_i \sum_r d_i^r H_i^r + \sum_i \sum_k \sum_r y_{ik}^r G_{ik}^r$$

Equation 4.1 – Optimization Model

The model is subject to the following constraints:

1. $E_i^r + I_i^r \leq H_i^r \qquad \forall\, r$ and i
2. $\sum_r H_i^r \leq Q_i^r \qquad \forall\, i$
3. $\sum_r X_{ij}^r \leq T_{ij} \qquad \forall\ i$ and j
4. $\sum_k G_{ik}^r \leq EH_i^r + H_i^r \qquad \forall\, r,\ i\ and\ k$
5. $\sum_i \sum_r G_{ik}^r = D_k \qquad \forall\, r,\ i\ and\ k$

Where endogenous variables are:

E_i^r : amount of commodity *r* exported from terminal *i*;

I_i^r : amount of commodity *r* imported through terminal *i*;

G_{ik}^r: amount of commodity *r* drayed between intermodal terminal *i* and regional centre *k*.

EH_i^r : excessive amount of commodity *r* that cannot be handled with the existing capacity of terminal *i*. If this amount is greater than 0, this suggests the optimum expansion of terminal *i* for handling *r*;

H_i^r: amount of commodity *r* handled within the current capacity of terminal *i*. If the volume of commodity reaches Q_i^r, maximum terminal capacity, then a separate calculation will suggest optimum expansion of terminal *i* (EH_i^r) as described above;

T_{ij}: total amount of commodity transported between terminals *i* and *j*.

Exogenous variables and corresponding values are:

a_{ij} : transportation cost for shipping unit amount of commodity between terminals *i* and j. Unit user cost, \$ / ton / mile (\$ is US dollars). The cost data is available for each Class I railroad operating in the US from the STB;

D_k: market demand at regional economic centre *k*;

d_i^r : handling cost (user cost per unit amount of commodity *r* at terminal *i* (based on STB data);

e_i^r : annual equivalent construction cost for handling unit excess amount of commodity *r* at terminal *i* (based on STB data);

Q_i^r : handling capacity of commodity *r* at terminal *i* per year converted to month for use in this dissertation;

q : Number of tracks x trains per day x 240 containers per train x maximum 53' container capacity of 28 tonnes x 365 days / month;

X_{ij}^r : amount of commodity *r* shipped from terminal *i* to terminal *j*; and

y_{ik}^r: drayage cost between the terminal *i* and regional centre *k*.

4.3 Baseline Scenario

The "Baseline Scenario" is intended to represent how commodities flow over the 7 Class I railroads between Canada and the United States in both directions. In the subsequent sections and the next chapter, there is discussion about how the "Baseline Scenario" can be modified to model scenarios such as adding a full-scale intermodal facility to somewhere on the rail network or introducing a small-scale intermodal technology into the rail network. Several tests were run on the "Baseline Scenario" for both Part I and Part II of the model to test for fidelity of results. For Part I, the tests involved running a network analysis with pairs of origins and destinations using known intermodal routes (i.e. CN's Prince Rupert to Chicago, UP and BNSF's respective routes from Los Angeles/Long Beach connecting with CN or CP in Chicago and on to Toronto, routes from Savannah, GA to Toronto, primarily on CN) to ensure that the routes made sense and followed the real-world routes.

The central assumption is that all rail traffic on Class I Railroads in Canada and the USA contains both domestic and international commodity flows. At least 42% of rail traffic in the USA originates or terminates at an international location (American Association of Railroads, 2020). This means the 42% of rail traffic in the USA originates or terminates in Canada or Mexico. It is important to note the 42% figure only includes trips that cross a border to or from the USA by rail. While a large quantity of cross-border trips enter the USA at seaports, these are not analyzed in this dissertation research. It is important to note that the research in this dissertation serves as the proof of principle for when more comprehensive data becomes available so that this assumption can be removed. As the detailed data is not available in the public domain it remains essential to use this central assumption. This is an example of how the Class I railroads could benefit from this type of research and apply the model and the findings towards their operations.

For Part II, as the model data set uses only international commodity flows, the issue of domestic flows impacting the model's results was tested by adding Freight Analysis Framework 4 (Centre for Transportation Analysis, Oak Ridge National Laboratories, 2018) data from 2017 for US domestic origin and destination pairs to test for capacity issues. The following assumptions were made to use the FAF4 data to represent domestic commodity flows:

1. Average of value per 53-foot container equivalent for all commodity groups is used;
2. Proportion of commodities shipped internationally is the same as commodities shipped domestically;
3. Proportion of commodities shipped domestically in Canada is the same as the proportion of commodities shipped domestically in the USA.

Domestic commodity flows were represented by adding the value of domestic shipments weighted proportionately by each terminal in each state/province to the value of international shipments for each terminal in each state/province. The results from the "Baseline Scenario" are shown in the following Tables 4.2 and 4.3 and Figure 4.3. As shown in Table 4.3, the total number of 53-foot intermodal container equivalents shipped internationally between Canada-US was estimated at 34,342 for the month of June, 2017 in the Baseline Scenario. It is unlikely that there would be capacity issues at full-scale intermodal terminals given that such facilities commonly have capacities measured in the hundreds of thousands of containers.

Table 4.2 – Objective Function Result for the Baseline Scenario

Transportation Costs	Terminal Operating Costs	Ontario Drayage Costs	Total Optimized Cost
$ 8,965,262.64 (30%)	$ 15,841,479.00 (54%)	$ 4,667,285.35 (16%)	$ 29,474,026.99 (100%)

Table 4.3 – Number of 53-foot Equivalent Intermodal Containers Between Canada and the USA Drayed Between Existing Ontario Intermodal Terminals in the Greater Toronto Hamilton Area and Ontario Economic Regions

Location	CN Brampton	CN Malton	CN Mississauga	CP Vaughan	Total
Chatham-Kent	0	0	0	276	276
Toronto	5865	0	10321	1189	17375
Hamilton-Niagara Peninsula	0	0	0	2116	2116
London	0	0	0	1774	1774
KWCG	0	0	0	1449	1449
Brockville	0	272	0	0	272
Ottawa	0	3264	0	0	3264
Kingston-Pembroke	0	1237	0	0	1237
Niagara	0	0	0	1213	1213
Muskoka-Kawarthas	0	1023	0	0	1023
Sarnia	0	0	0	343	343
NorthEast	395	1090	0	0	1485
Windsor	0	0	0	1080	1080
Stratford-Bruce Peninsula	0	0	0	807	807
NorthWest	627	0	0	0	627
Total	6887	6887	10321	10247	34342

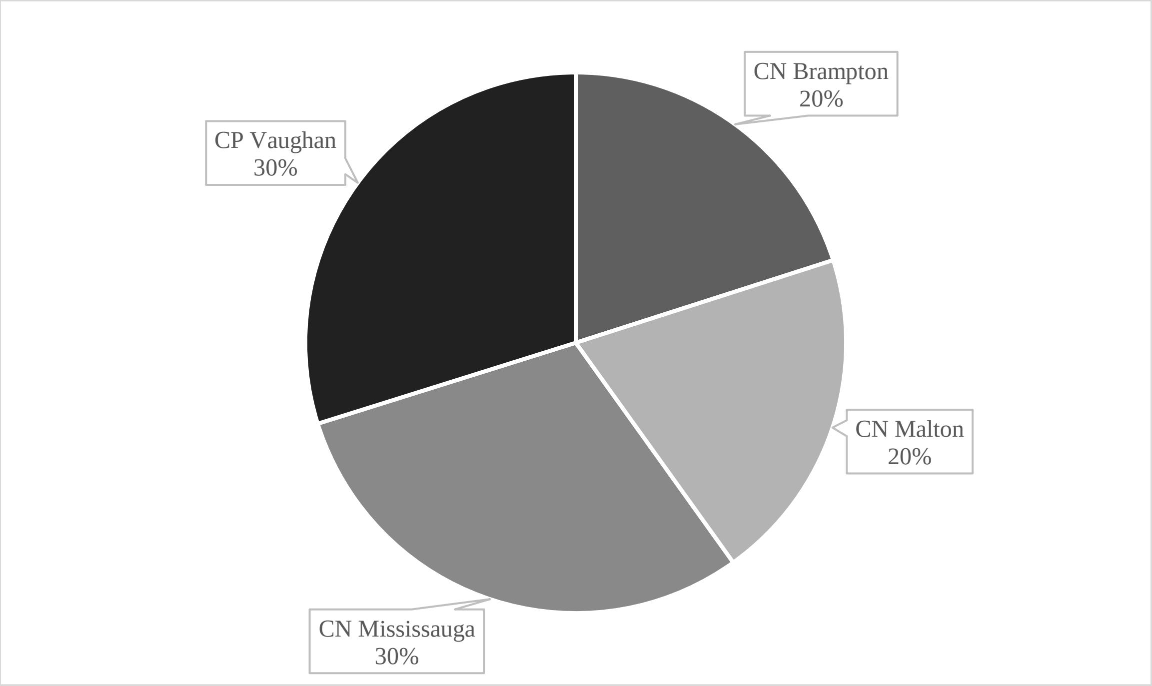


Figure 4.3 – Estimated Baseline Share – Canada-US Commodities Shipped by Rail to the Existing Ontario Intermodal Terminals in the Greater Toronto Hamilton Area

In the absence of other publicly available data the author deems this assessment of the "Baseline Scenario" demonstrates the model to be suitable for exploring other scenarios. The results from the "Baseline Scenario" are compared with the results from the "Full-Scale Intermodal Scenario" later in this Chapter.

4.4 Full-Scale Intermodal Scenario

The "Full-Scale Intermodal" scenario involves the creation of one or more new full-scale intermodal terminals on the network. The purpose of this scenario is to test if the new intermodal terminal(s) will result in changes to the commodity flows across the North American Class I railroad system. As there is not a full-scale intermodal facility closer than the Greater Toronto-Hamilton Area (see Figure 4.4) on the Canadian side of the border at Windsor-Detroit, this scenario examines the hypothetical addition of a new intermodal terminal near the existing CP Walkerville Yard in Windsor, ON. The CP Walkerville Yard is located relatively close to the international rail tunnel along the mainline between Detroit, MI and Toronto, ON (see Figure 4.5). Presently the CP Walkerville Yard primarily serves the local automotive sector and additionally serves as a local interchange point with CN. An image is shown as an example of a full-scale intermodal terminal in Figure 4.6.

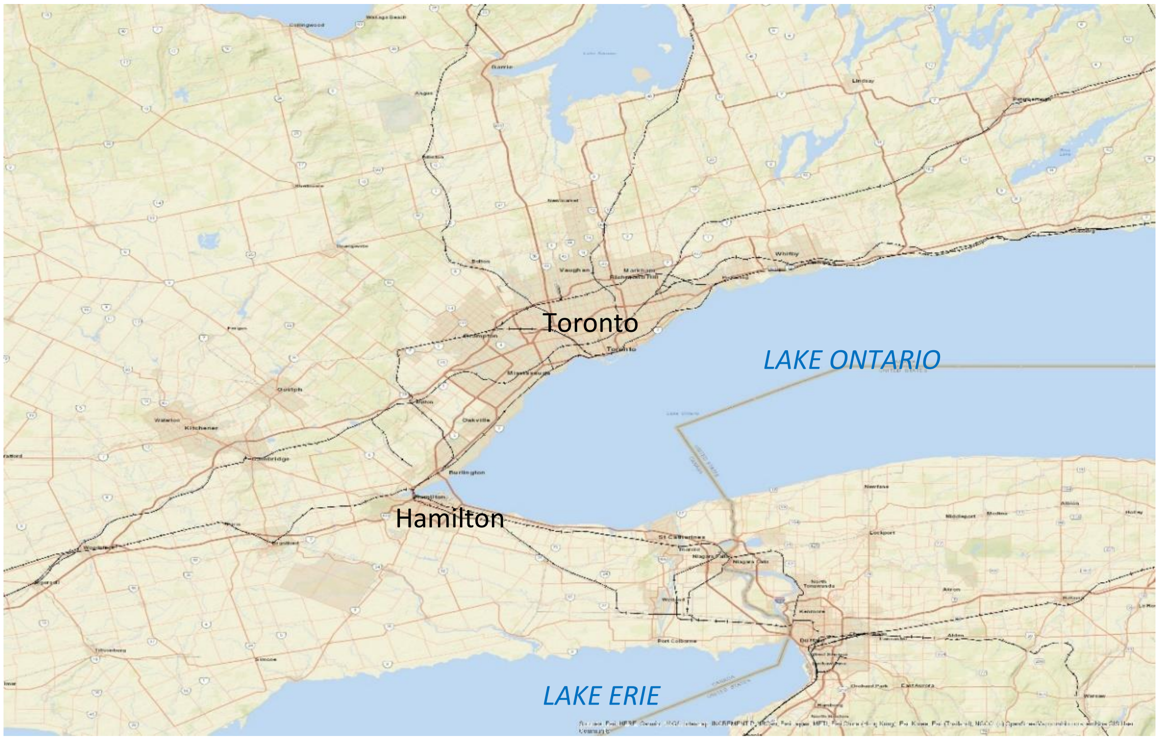
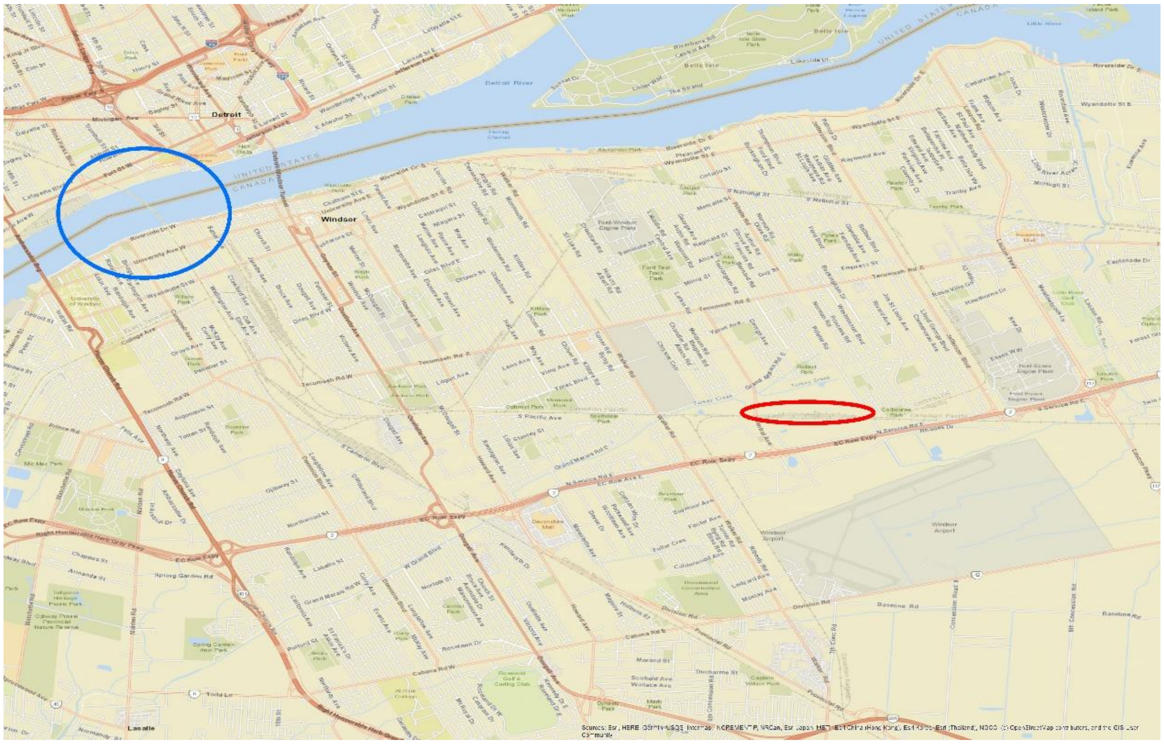


Figure 4.4 – Greater Toronto Hamilton Area of Southern Ontario



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

Figure 4.5 – Location of Windsor-Detroit Rail Tunnel (blue circle) and CP Walkerville Yard (red ellipse).

Figure 4.6 – Example of a Full-Scale Intermodal terminal, Source: www.stvinc.com

The economics of a full-scale intermodal terminal in Windsor-Essex would need to be justified based on patterns of demand for what is produced and consumed in the region. In terms of production Windsor-Essex is known for transportation equipment, manufacturing and agri-food. While all three sectors use trucks for transporting their products, the transportation equipment sector is the biggest rail user for shipping their products from the area. It is noted that a substantial component of the transportation equipment crossing the border is in the form of finished vehicles. It may be possible that vehicle parts or partially assembled components of vehicles could be shipped via an intermodal container. Unless assembly processes were to change, it is unlikely that this would account for a substantial amount of the value shipped cross-border.

Additionally, a trans-loading market has emerged in the region with such firms developing along existing rail sidings. In terms of consumption, industry and commerce there is a continuous flow of intermodal containers being delivered to locations of business by truck from full-scale intermodal terminals all over the mid-western US and the Highway 401/Autoroute 20 corridor between Windsor and Montreal. The question that the "Full-Scale Intermodal Scenario" answers is if a full-scale intermodal terminal is built in Windsor-Essex, would it be used for cross-border container traffic?

4.5 Implementation

The model is comprised of two parts as discussed in the previous chapter:

(i) A doubly constrained gravity model that depends on a GIS-based network optimization with route assignment; and

(ii) A linear programming model.

The data used in the above parts can be customized to meet the needs of the scenario being modeled. For example, additional terminal *i*'s representing origins or destinations could be added or removed to test for the impacts on the system. In the case of the GIS network this is involves editing the point, line and attribute data that form the GIS network data set and re-running the GIS-based network optimization with route assignment. At present this is not a trivial task and requires manual editing though in the future there is opportunity to automate many components of this part using scripting languages included with GIS software. The linear programming model can be customized so that it can process additional or fewer terminal i*'*s representing origins or destinations by adding or removing columns and amending the cell references in the spreadsheet functions and the linear optimization model accordingly. While less time intensive than the GIS-based network model, this is still not a trivial task and has potential to be automated in the future. An overview of how the linear programming model can be customized is discussed in the following section. It is noted that automating the above processes is beyond the scope of this dissertation.

The linear programming model is built using a set of modified origin-destination matrices for the variables with additional columns and matrices for the calculation of constraint testing and the solution. The mathematical model shown in Equation 4.1 generates data that is used in an additional calculation that needs to be completed to determine if a location is feasible for a full-scale intermodal terminal. One of the outputs from the model is the H_i^r variable. By converting the amount of H_i^r to the equivalent number of 53-foot intermodal containers handled by the terminal per month and dividing by the number of days in the month to obtain the number of lifts per day *C*, the feasibility can be assessed. A full-scale intermodal terminal requires between 650 and 1,000 lifts per day to be feasible. If *C* is greater than or equal to the minimum requirement of 650 lifts per day, then a full-scale intermodal terminal could be feasible at a particular location on the rail network. If C is less than 650 lifts per day, then a full-scale intermodal terminal would not be feasible at a particular location on the rail network.

The objective function is expressed with the sum of three terms, Term 1 being the calculation of total existing optimized costs in the system $minimize \sum_{ij}\left(a_{ij} T_{ij}\right)$, Term 2 being the calculation of total optimized terminal expansion costs required for an optimal system $minimize \sum_i \quad \sum_r \quad \left(d_i^r H_i^r\right)$ And Term 3 being the calculation drayage costs to the selected regional centres $minimize \ \sum_i \sum_k \sum_r y_{ik}^r G_{ik}^r$.

4.6 Results

A hypothetical site was added to the CP system near the Walkerville Yard based on a typical 400-acre facility with a daily capacity of 1,000 trucks per day (30,000 trucks per month) at a development and construction cost of $250 million USD amortized over 20 years. All other aspects of the Baseline scenario remained the same. At a typical full-scale intermodal facility with 1,000 lifts per day x 365 days per year x 20 years of amortization of the $250 million USD that would mean approximately 7.3 million lifts over the 20 years lifespan of the intermodal terminal infrastructure. Based on these figures, the cost of a lift at 1,000 lifts per day over the lifetime of the facility would require a minimum lift charge of $34.25 USD to pay for the facility, excluding any interest charges. If there were fewer lifts, then the cost per lift would increase, thus necessitating higher lift charges. The $34.25 USD lift charge noted above is lower than the lift charges identified by all North American Class I railroads based on the 2017 URCS data. With Windsor generating approximately 56 lifts per day (1,699 lifts per month) based on the observed data, an additional 594 lifts per day (19,260 lifts per month) would be required to make a full-scale intermodal terminal viable to achieve the minimum lift threshold of 650 lifts per day (19,500 lifts per month) to achieve viability..

The results generated in this dissertation research represent a proof of principle or a demonstration that the results are feasible and demonstrate a fundamental framework that can be applied to other scenarios. This is achieved in the full-scale intermodal scenario by identifying how many intermodal container lifts would be generated if a full-scale intermodal facility was added a specific point on the network in Windsor, Ontario. The same fundamental framework could be applied to one or more locations on the Class I rail network to determine if a potential new intermodal facility could be viable and to identify potential impacts on flows going to existing intermodal facilities on the network. This will be further explored in a subsequent section of this dissertation.

Table 4.4 – Estimated Value per 53-foot Intermodal Container based on 2017 Commodity Cost by Weight.

R	BTS Groups	Cost / lb (USD)	Value per 53' IM Container (56,750lbs)
1	01-05	$ 5.17	$ 293,397.50
2	06-15	$ 0.67	$ 38,022.50
3	16-24	$ 1.28	$ 72,640.00
4	25-27	$ 0.28	$ 15,890.00
5	28-38	$ 0.63	$ 35,752.50
6	39-40	$ 2.24	$ 127,120.00
7	41-43	$ 7.14	$ 405,195.00
8	44-49	$ 0.59	$ 3,482.50
9	50-63	$ 7.51	$ 426,192.50
10	64-67	$ 18.88	$ 1,071,440.00
11	68-71	$ 2.95	$ 167,412.50
12	72-83	$ 1.59	$ 90,232.50
13	84-85	$ 18.58	$ 1,054,415.00
14	86-89	$ 9.65	$ 547,637.50
15	90-97	$ 13.17	$ 747,397.50
16	98-99	$ 7.49	$ 425,057.50

Table 4.5 – Comparison of Baseline vs. Modeled Quantity of 53-foot Intermodal Container Equivalents at Full-Scale Intermodal Terminals with the Addition of a Hypothetical New Terminal at Windsor.

Location	Baseline	Modeled
CN Brampton	6,887	6,886
CN Malton	6,887	6,886
CN Mississauga	10,321	10,319
CP Vaughan	10,247	8,552
CP Windsor	0	1,699

Table 4.6 – Objective Function Result for the Windsor Full-Scale Intermodal Scenario

	Transportation Costs	Terminal Operating Costs	Ontario Drayage Costs	Total Optimized Cost
Baseline	$ 8,965,262.64	$ 15,841,479.00	$ 4,667,285.35	$ 29,474,026.99
Full-Scale	$ 8,965,262.64	$ 15,943,276.73	$ 4,157,489.72	$ 29,066,029.08

The results shown in Table 4.6 represent the components of the Objective Function previously discussed in Chapter 3 of this dissertation. With the introduction of a hypothetical full-scale intermodal terminal in Windsor it is observed that the Terminal Operating Costs component increases by approximately $100,000 per month (cross-border rail intermodal shipments only) and the Ontario Drayage Costs decrease by approximately $500,000 (cross-border intermodal shipments only) resulting in a decrease in the Total Optimized Cost of approximately $400,000 per month. Given the relatively small number of containers that shift to the hypothetical full-scale intermodal terminal in Windsor, the results seem reasonable.

Table 4.7 – Number of 53-foot Equivalent Intermodal Containers Between Canada and the USA Drayed Between Ontario Intermodal Terminals in the Greater Toronto Hamilton Area plus a hypothetical facility in Windsor and Ontario Economic Regions to the Ontario Economic Regions

Location	CN Brampton	CN Malton	CN Mississauga	CP Vaughan	CP Windsor	Total
Chatham-Kent	-	-	-	-	276	276
Toronto	5,863	-	10,319	1,193	-	17,375
Hamilton-Niagara Peninsula	-	-	-	2,116	-	2,116
London	-	-	-	1,774	-	1,774
KWCG	-	-	-	1,449	-	1,449
Brockville	-	272	-	-	-	272
Ottawa	-	3,264	-	-	-	3,264
Kingston-Pembroke	-	1,237	-	-	-	1,237
Niagara	-	-	-	1,213	-	1,213
Muskoka-Kawarthas	-	1,023	-	-	-	1,023
Sarnia	-	-	-	-	343	343
NorthEast	396	1,089	-	-	-	1,485
Windsor	-	-	-	-	1,080	1,080
Stratford-Bruce Peninsula	-	-	-	807	-	807
NorthWest	627	-	-	-	-	627
Total	6,886	6,886	10,319	8,552	1,699	34,342

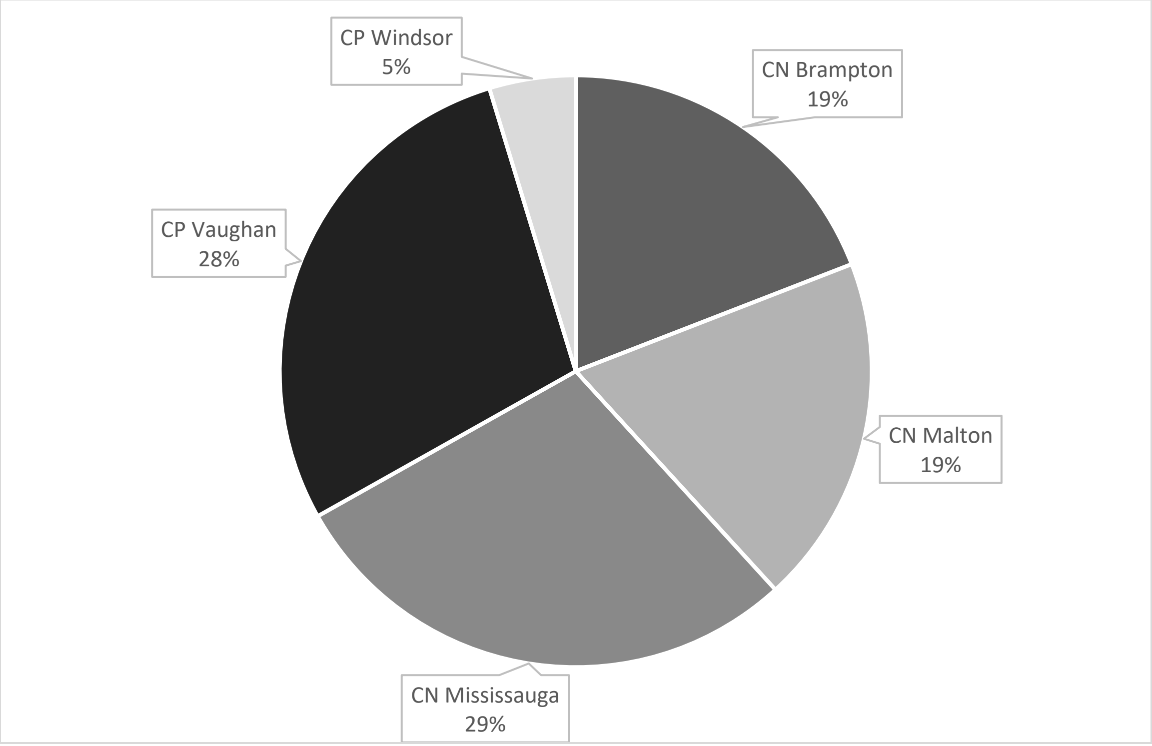


Figure 4.7 – Percentage of Commodities Shipped To/From the Existing Ontario Intermodal Terminals in the Greater Toronto Hamilton Area with the Addition of a Full-Scale Intermodal Terminal in Windsor.

The results of the "Full-Scale Intermodal Scenario" with the Windsor-Essex example showed that some cross-border commodity flows changed from the Baseline scenario. The results displayed in Table 4.1, Table 4.2 and Figure 4.7 demonstrate the flows going to or from the Windsor. Table 4.3 shows that amount of cross-border commodities shipped to/from the existing Ontario intermodal terminals with the addition of a full-scale intermodal terminal in Windsor. Table 4.4 shows the change in cross-border commodity flows at the existing Ontario intermodal terminals with the addition of a full-scale intermodal terminal in Windsor. Sarnia and Chatham-Kent Ontario Economic Regions would be served by a full-scale intermodal terminal for cross-border container traffic in Windsor if such a facility was developed. This answers the question would any shippers use it with the answer yes. Would it be economically viable though? If we look at the type and amount of cross-border commodities that flow through existing full-scale intermodal terminals in the Greater Toronto Hamilton Area, the amounts of international traffic are at least 3 times greater than amount of commodity traffic that a full-scale intermodal terminal at Windsor would generate and the type of commodities assigned to Windsor then we can gain some insights. This amount excludes domestic container flows between Canadian terminals which is substantial considering the daily intermodal trains between the deep-water ports at Vancouver, Prince Rupert and Montreal to other Canadian intermodal terminals in Toronto, Winnipeg, Edmonton and Calgary. The model has assigned 1,699 53-foot equivalent containers to the full-scale intermodal terminal in Windsor per month. With only 1,699 lifts per month a full-scale intermodal terminal would not be economically feasible as the cost per lift in Windsor would be at least $59.90 USD which translates into approximately $102,000 per month in lift revenue. Given the typical $250 million USD cost of a developing a full-scale intermodal terminal, the potential revenue generation makes a full-scale intermodal terminal in Windsor infeasible under existing market conditions. It is generally accepted that a full-scale intermodal terminal can be economically feasible if there are at least 650 to 1,000 lifts per day or 20,000 to 30,000 lifts per month. Unless market conditions change so that Windsor, Sarnia and Chatham-Kent ship or receive 20,000 to 30,000 containers per month, it makes more sense to continue shipping cross-border intermodal containers to other terminals and draying the containers to Windsor, Sarnia and Chatham-Kent instead of building a full-scale intermodal terminal in Windsor.

Furthermore, there is sufficient capacity at the existing facilities in the Greater Toronto-Hamilton Area to support demand the existing demand for rail-truck intermodal based on the USDOT BTS 2017 figures. Therefore, the answer to the question posed at the beginning of this chapter is that if a full-scale intermodal terminal was built in Windsor-Essex for cross-border container traffic, it would see limited use and would not be economically feasible. The next chapter will examine possibilities for cross-border intermodal with the introduction of a small-scale intermodal technology

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CHAPTER 5

SMALL-SCALE INTERMODAL TECHNOLOGY

5.1 Introduction

Small-scale intermodal technology is as the name suggests a smaller version of the full-scale intermodal that was discussed in the previous Chapter. A key advantage of small-scale intermodal is that it doesn’t require a large intermodal terminal to deploy, rather it could be as simple as a rail siding built in combination with a roadway. While less common currently in North America, small-scale intermodal has developed acceptance in the European context with the deployment of the multi-swing rail car, now referred to as the “HELROM Wagon” which is discussed in following sections of this Chapter. In Europe, policy decisions to mitigate the impacts of climate change by reducing greenhouse gas emissions is contributing to the shift towards small-scale intermodal. Additionally, shorter travel distances between European origin-destinations pairs and major terminals also contributes to potential of small-scale intermodal. A summary of literature about rail intermodal in the European context is provided earlier in this dissertation. In the North American context, small-scale intermodal could prove viable for modal shift from point-to-point trucking intermodal given the lower fixed capital costs compared to full-scale intermodal terminals and growing concerns about greenhouse gas emissions. While rail is generally recognized as being more cost-efficient than trucking for distances beyond 800 kilometers, small-scale intermodal has the opportunity to change the viability of rail for shorter distances between terminals.

This dissertation marks the first examination of small-scale intermodal in the North American and Canada-US context. Small-scale intermodal between Canada and the US is examined by looking at how a model using a doubly constrained gravity model that depends on a GIS-based network optimization with route assignment and a linear programming model can be deployed to identify if the economics of cross-border commodity flows using small-scale intermodal would make sense in Ontario Economic Regions (see Figure 5.1).

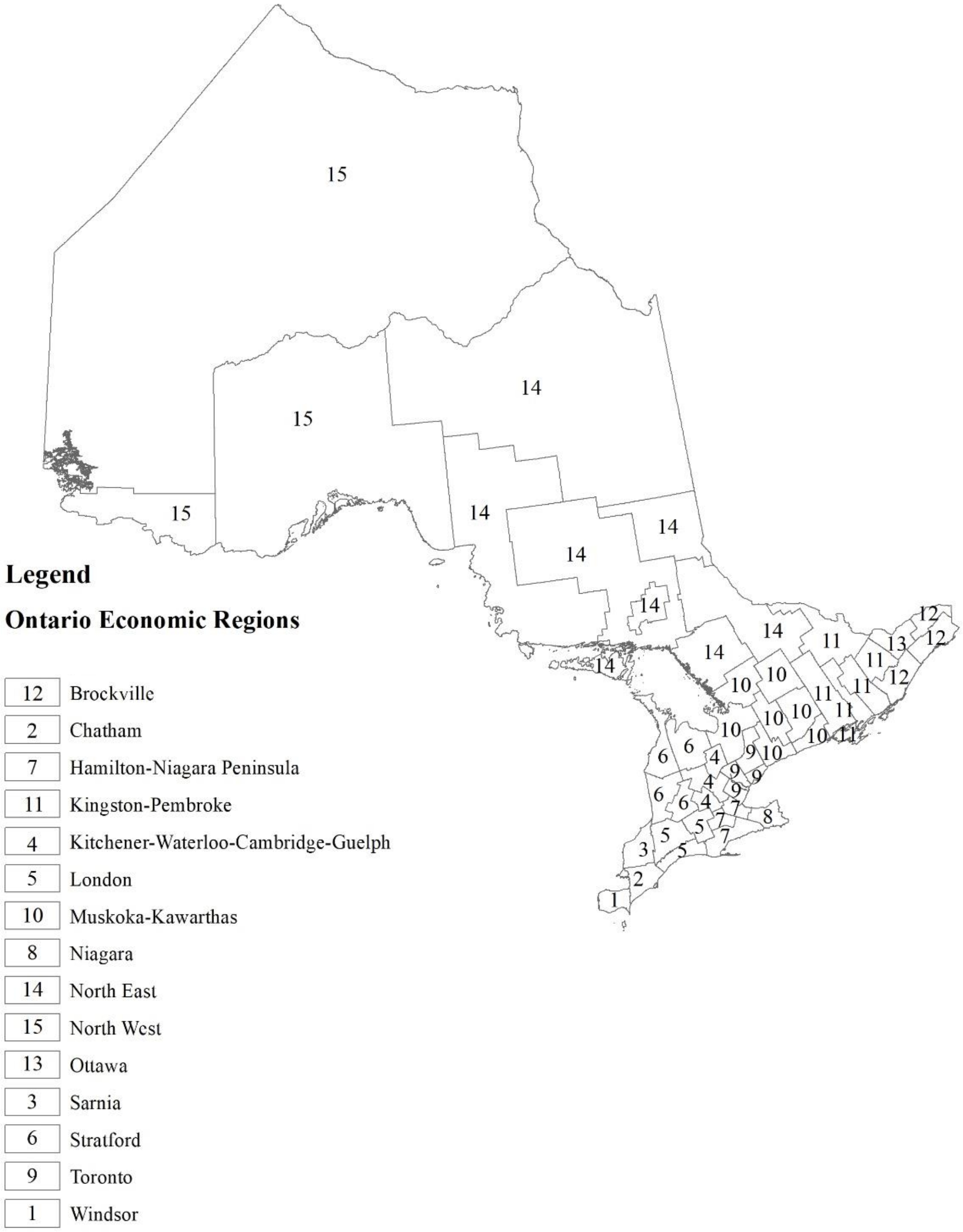

Figure 5.1 – Ontario Economic Regions

Testing if small-scale intermodal implementation would result in changes to cross-border rail intermodal commodity flows between Canada and the US to or from Ontario Economic Regions can be accomplished by applying the model described in Chapter 3 of this dissertation and removing the capital costs associated with the development of a full-scale intermodal terminal. For the purposes of this test, it is assumed that widespread adoption of small-scale intermodal occurs throughout the Ontario Economic Regions. It is hypothesized that deploying small-scale intermodal in the Ontario Economic Regions will result in lower total transportation costs, particularly with lower drayage costs resulting from small-scale intermodal facilities located closer to where the cross-border commodities will be produced or consumed in Ontario.

5.2 History of Rail-Truck Intermodal in North America

Rail-truck intermodal operations date back to the 1950's with the first regular service of trailer-on-flat-car (TOFC) and container-on-flat-car (COFC) being offered by some Class I railroads. Containers were loaded onto flat cars using cranes that were designed for other purposes. Shipping with containers was not limited to rail and truck. In what would become the company known as SeaLand, a shipping service was created to haul standardized containers by road, rail and ship between US Atlantic, Gulf of Mexico, Caribbean and European ports. The company would eventually become part of CSX Transportation before being acquired by the Maersk Line in 1999 (Maersk, 2021). The innovation of the standardized shipping container for SeaLand would eventually evolve into what became the globally standard 20-foot shipping container and lead to the now industry common term of the twenty-foot equivalent unit or TEU.

In the 1960’s and 1970’s the operational innovation of “circus” loading of trailer units onto TOFC trains was a common sight across the US and Canada. Long trains of flat cars with temporary ramps covering the gaps between flat cars allowed for trailers to be backed up a ramp and onto flat cars, detached from the truck and then supported by the trailers’ legs and a folding trailer hitch that was built into the flat car. The truck would then drive off and the next trailer would be backed on until the train was loaded (see Figure 5.2). At the destination, the process was reversed and a truck would back on to each trailer and drive off the train until the train was unloaded. With the crane technology at the time, “circus” loading of trailer units was more efficient and a less costly alternative except in large seaports.

Figure 5.2 – Circus Style Loading/Unloading TOFC. Source: www.carrtracks.com and Ask Media Group

In late 1960's the introduction of the gantry crane (see Figure 5.3) was an innovation that changed rail-truck intermodal and updated models of this technology continue in use at many terminals and industries today. The gantry crane is a technology that allows the crane to move above two or more adjacent paths such as a roadway, railroad tracks or ship and lift a container or trailer from one mode or vehicle to another. These gantry cranes are typically supported on rubber tires for use on roads or on wheels designed for rails. The rail mounted version of the cranes have been more common at larger intermodal facilities where as the rubber tire mounted cranes can be found at both large and small terminals. The movement of the gantry crane provides for an efficient means of loading or unloading an entire parked train with the crane moving from rail car to rail car. In a full-scale intermodal terminal many such gantry cranes may be found in addition to other lifting technologies. At sea ports serving rail intermodal it is common to see very-large rail mounted gantry cranes that can transfer intermodal containers between large ocean-going vessels and lengthy COFC trains.

Figure 5.3 – Mi-Jack Rubber Tired Gantry Crane, Source: Mi-Jack Products, www.mi-jack.com

Another innovation in intermodal container transfer between modes became common place around intermodal terminals in the 1980's: the lift truck (see Figure 5.4).

Figure 5.4 – Lift Truck. Source: Kone Cranes www.konecranes.com/en-ca/industries/container-handling/intermodal

Lift trucks are specialty trucks with an extendable hydraulic arm that can be fitted with a variety of attachments for performing various tasks. For loading containers or trailers, lift trucks are fitted with devices that can pickup a container or trailer from above or below depending on the configuration and circumstances that they are deployed in. In Lift trucks have been deployed in North America at both large-scale intermodal terminals and small one or two track local facilities.

In the 1990's a new innovative technology was developed in Sweden based on technology originally proposed in Finland that brought a different perspective on rail-truck intermodal transportation: the Megaswing rail car, a technology that put the loading mechanism for a trailer into the rail car rather than relying on an external loading device (BESTFACT

Consurtium, 2013). The Megaswing railcar, now known as the HELROM wagon, has a hydraulic system built into the rail car that allows a portion of the chassis to swing out to either side and lower to a road surface that is adjacent to the railroad track (see Figure 5.5). This allows for a trailer or an intermodal container on a trailer chassis to be backed onto the rail car and then locked into position for transport to its destination. Upon arrival at the destination, the process is reversed and a truck connects to the trailer to unload. Initially deployed in Sweden as part of a cost-efficient small scale intermodal operation (Kordnejad 2012, Kordnejad 2014), in 2019 the Megaswing technology and accompanying patents were purchased by the German company Helrom.

Figure 5.5 – Megaswing Railcar / HELROM Wagon. Source: https://www.handelsblatt.com/unternehmen/handel-konsumgueter/helrom-dieses-start-up-will-mit-seiner-trailerbahn-den-gueterverkehr-revolutionieren/25565156.html?ticket=ST-379845-tPqDebDMrgGRJ9SUxEa7-ap2

In April 2020, Helrom launched scheduled intermodal rail service using the Megaswing railcars between Germany and Austria (Burroughs, 2020). The Megaswing technology is currently being investigated by Class I railroads and government agencies for potential future applications in North America. The following sections of this dissertation explore potential application of a small-scale intermodal technologysuch as Megaswing for the provision of small-scale intermodal in areas where full-scale intermodal is not feasible, such as in the Winsor-Essex, Ontario context.

This section has included an overview of how intermodal rail service has changed since the 1950's. It is acknowledged that the location of intermodal facilities has changed over this timeframe and that reflects on the type of intermodal rail services provided. Early intermodal services were typically based at existing freight terminals that had cranes or were simply ramps that allowed for trailers to be backed onto flat cars, see Figure 5.2 above. As intermodal services evolved in the 1970's and 1980's railroads moved intermodal capabilities from existing terminals in favour of dedicated intermodal terminals equipped with a variety of container or trailer lifting mechanisms (see Figures 5.3 and 5.4 above) located on large tracts of land in suburban areas with close proximity to existing rail corridors and major highways. In terms of building train consists these full-scale intermodal terminals typically generate or receive long intermodal trains in the order of magnitude of 250 intermodal containers.(see Figure 4.6 in the previous Chapter). The site selection of the locations of intermodal terminals has largely been at the discretion of the Class I Railroads (such as Cando Rail Services, undated). By the 2000's it has become more common to see clusters of full-scale intermodal terminals within the same general geographic area – examples include Chicago, Los Angeles/Long Beach and Toronto. The intermodal terminals in the Toronto, Ontario vicinity were discussed earlier in this dissertation. By the 2010’s as railroads were looking for operating efficiencies and started the practice of combining 2 or 3 intermodal trains together with locomotives distributed throughout the long consists including at both ends of a consist to provide consisting braking capability and to optimize the distribution of forces throughout the train to avoid issues such as derailments and broken couplers. Innovative freight car technologies such as the Megaswing railcar / HELROM wagon in use in Europe now have the potential to change both rail operations and how and where intermodal terminals are developed.

5.3 Methods of Analysis

In terms of production, Windsor-Essex is known for transportation equipment, manufacturing and agri-food. While all three sectors use trucks for transporting their products, the transportation equipment sector is the biggest rail user for shipping their products from the area (USDOT BTS, 2018). Additionally, a truck-rail trans-loading market is emerging in the region with such firms developing along existing rail sidings. In terms of consumption, industry and commerce there is a continuous flow of intermodal containers being delivered to locations of business by truck from full-scale intermodal terminals all over the mid-western US and the Highway 401/Autoroute 20 corridor between Windsor and Montreal. While some of these containers originate or terminate in Windsor, most are passing through to and from other origins and destinations.

With the mode shift to truck that has occurred over the past several decades, industry in Essex County ships using intermodal containers or transloads to a different mode in order to enjoy the benefit of shipping goods by a cost-friendly long-distance mode such as rail or sea. This containerized cargo ultimately connect through intermodal facilities in the

Greater Toronto Hamilton Area or the US. Goods produced in the Windsor-Essex region are ultimately containerized and connect through intermodal terminals in the Greater Toronto Area or the US. The Windsor-Essex situation is an example of where a small-scale intermodal technologysuch as Megaswing that uses standardized equipment could provide benefits to industry in Essex County.

The analysis is conducted using the optimization model shown below in Equation 5.1, described in section 5.2.

The objective function that is used in the implementation of the model is expressed with the sum of three terms, Term 1 being the calculation of total existing optimized costs in the system $minimize \sum_{ij}(a_{ij}T_{ij})$, Term 2 being the calculation of total optimized terminal expansion costs required for an optimal system $minimize \sum_{i} \quad \sum_{r} \quad (d_i^r H_i^r)$ And Term 3 being the calculation drayage costs to the selected regional centres $minimize \ \sum_i \sum_k \sum_r y_{ik}^r G_{ik}^r$. The weights for distributing commodity flows to the Ontario Economic Regions were calculated based on the assumption that amount of consumption at any Ontario Economic Region is proportional to the Region's population as a percentage of Ontario's total population. This results are displayed and discussed later in this chapter.

5.4 Small-Scale Intermodal Technology Scenario

The "Small-Scale Intermodal Technology Scenario" involves the creation of a small terminal comprised of an existing railroad track beside a roadway where Megaswing / HELROM Wagon technology could be deployed. The difference between the "Small-Scale Intermodal Technology Scenario" and both the "Baseline Scenario" and "Full-Scale Intermodal Scenario" is that the high costs of developing and constructing a typical intermodal terminal have been removed. For the purpose of a full-scale intermodal terminal, the capital costs can be considered as sunk costs. The purpose of "Small-Scale Intermodal Technology Scenario" is to test if the new small-scale intermodal technologycompatible terminals will result in changes to the cross-border commodity flows across the North American Class I railroad system.

As discussed in the previous chapter, full-scale intermodal is not currently viable in Windsor-Essex for cross-border container-traffic based on existing capacity elsewhere in the system and the cost of drayage to the existing full-scale intermodal terminals not being sufficient to shift users to a Windsor-Essex full-scale intermodal terminal.

5.5 Implementation

The model is comprised of two parts as discussed in Chapter 3:

(i) Doubly constrained gravity model that depends on a GIS-based network optimization with route assignment; and

(ii) Linear programming model.

The data used in the above parts can be customized to meet the needs of the scenario being modeled. For example, terminals representing origins or destinations could be added or removed to test for the impacts on the system. In the case of the GIS network this is involves editing the point, line and attribute data that form the GIS network data set and re-running the GIS-based network optimization with route assignment. At present this is not a trivial task and requires manual editing though in the future there is opportunity to automate many components of this part using scripting languages included with GIS software. The linear programming model can be customized so that it can process additional or fewer origins or destinations by adding or removing columns and amending the cell references in the spreadsheet functions and the linear optimization model accordingly. While less time intensive than the GIS-based network model, this is still not a trivial task and has potential to be automated in the future. An overview of how the linear programming model can be customized is discussed in the following section. It is noted that automating the above processes is beyond the scope of this dissertation.

The linear programming model is built using a set of modified origin-destination matrices for the variables with additional columns and matrices for the calculation of constraint testing and the solution. The spreadsheet structure is included in Appendix 'C'.

5.6 Results and Discussion

Small-Scale Intermodal Technology Scenario

This scenario assumes widespread adoption of Megaswing rail cars using sidings adjacent to roadways at existing full-scale intermodal terminals and at regional centres of the Ontario Economic Regions. All other aspects of the "Baseline Scenario" remained the same including the assumption that the terminals can handle the same number of Megaswing lifts as any existing facility. The only fee would be the lift cost that the railroad charges to load/unload the trailer or container on trailer chassis. It is acknowledged that existing full-scale intermodal terminals have substantial sunk infrastructure costs and that small-scale intermodal technology would be deployed for the addition of new capacity or as the replacement for infrastructure that has passed the end of its service life.

The results of the "Small-Scale Intermodal Technology Scenario" are presented in Tables 5.1, 5.2, 5.3 and 5.4, and Figure 5.6 demonstrate several changes in commodity flows from the Baseline scenario. The results show that the small-scale intermodal technology would result in greater amounts of cross-border commodity flows to the small and mid-sized communities and decreases from the existing full-scale intermodal terminals. While there is sufficient capacity at the existing facilities in the Greater Toronto-Hamilton Area (see Figure 5.7) to support the existing demand for rail-truck intermodal based on the USDOT BTS 2017 figures the results show that it would be more economic to move intermodal traffic to facilities served by the small-scale intermodal technology.

Table 5.1 – Objective Function Result for the Small-Scale Intermodal Technology Scenario

	Transportation Costs	Terminal Operating Costs	Ontario Drayage Costs	Total Optimized Cost
Baseline	$ 8,965,262.64	$ 15,841,479.00	$ 4,667,285.35	$ 29,474,026.99
Small-Scale	$ 8,965,262.64	$ 15,842,273.28	$ 575,885.07	$ 25,383,420.99

The Objective Function results for the Small-Scale Intermodal Technology Scenario are shown in Table 5.1. A discussion about the Objective Function is included in Chapter 3 of this dissertation. By introducing small-scale intermodal technology we observe a slight increase in Terminal Operating Costs that is offset by a substantial decrease in Ontario Drayage Costs of approximately $4 million per month resulting in a similar reduction in the Total Optimized Cost. The slight increase in Terminal Operating Costs could be attributed to use of Class I Railroads closer to the hypothetical Ontario small-scale intermodal terminals while the decrease in Ontario Drayage Costs can be attributed to the hypothetical Ontario small-scale intermodal terminals being located closer to the origins or destinations. Building on the discussion of the results in Chapters 3 and 4 of this dissertation this also seems reasonable.

Table 5.2 – Breakdown of the 53-foot Equivalent Cross-Border Intermodal Containers Drayed Between Existing Ontario Intermodal Terminals with the Addition of Small-Scale Intermodal Technology Intermodal Service Sites and Ontario Economic Regions

Location	Chatham-Kent	Toronto	Hamilton-Niagara Peninsula	London	KWCG	Brockville	Ottawa	Kingston-Pembroke	Niagara	Muskoka-Kawarthas	Sarnia	NorthEast	Windsor	Stratford-Bruce Peninsula	NorthWest	Total
CN Brampton	0	6,886	0	0	0	0	0	0	0	0	0	0	0	0	0	6,886
CN Malton	0	6,886	0	0	0	0	0	0	0	0	0	0	0	0	0	6,886
CN Mississauga	0	3,603	0	0	0	0	0	0	0	0	0	0	0	0	0	3,603
CP Vaughan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CP Windsor	0	0	0	0	0	0	0	0	0	0	0	0	1,080	0	0	1,080
CN Capreol	0	0	0	0	0	0	0	0	0	0	0	1,485	0	0	627	2,112
CN Chatham	276	0	0	0	0	0	0	0	0	0	0	0	0	0	0	276
CN Hamilton Yd	0	0	2,116	0	0	0	0	0	0	0	0	0	0	0	0	2,116
CN London	0	0	0	1,774	0	0	0	0	0	0	0	0	0	807	0	2,581
CP London	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CP Hamilton	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CP Galt	0	0	0	0	1,449	0	0	0	0	0	0	0	0	0	0	1,449
CN Brockville	0	0	0	0	0	272	0	0	0	0	0	0	0	0	0	272
CN Ottawa	0	0	0	0	0	0	3,264	0	0	0	0	0	0	0	0	3,264
CN Kingston	0	0	0	0	0	0	0	1,237	0	0	0	0	0	0	0	1,237
CN St. Catharines	0	0	0	0	0	0	0	0	1,213	0	0	0	0	0	0	1,213
CP Peterborough	0	0	0	0	0	0	0	0	0	1,023	0	0	0	0	0	1,023
CN Sarnia	0	0	0	0	0	0	0	0	0	0	343	0	0	0	0	343
CP Sudbury	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	276	17,375	2,116	1,774	1,449	272	3,264	1,237	1,213	1,023	343	1,485	1,080	807	627	34,342

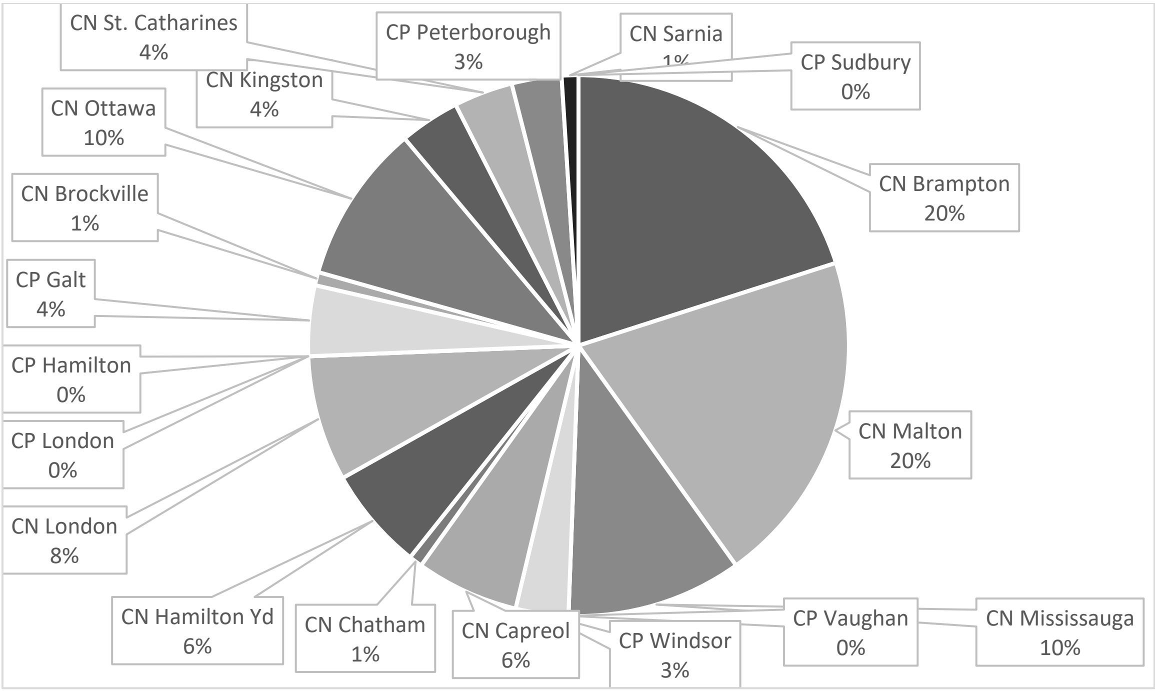

Figure 5.6 – Percentage of Cross-Border Commodities Shipped To/From the Existing Ontario Intermodal Terminals with the Addition of Small-Scale Intermodal Technology Intermodal Service Sites.

Table 5.3 – Number of 53-foot Equivalent Canada-US Intermodal Containers Shipped To/From the Existing Ontario Intermodal Terminals with the Addition of Small-Scale Intermodal Technology Intermodal Service Sites

Location	Canada-US Containers
CN Brampton	6,886
CN Malton	6,886
CN Mississauga	3,603
CP Vaughan	0
CP Windsor	1,080
CN Capreol	2,112
CN Chatham	276
CN Hamilton Yd	2,116
CN London	2,581
CP London	0
CP Hamilton	0
CP Galt	1,449
CN Brockville	272
CN Ottawa	3,264
CN Kingston	1,237
CN St. Catharines	1,213
CP Peterborough	1,023
CN Sarnia	343
CP Sudbury	0

Table 5.4 – Comparison of Baseline Scenario vs. Small-Scale Intermodal Technology Scenario for Number of 53-foot Equivalent Canada-US Intermodal Containers at Facilities With the Addition of Small-Scale Intermodal Technology

Location	Baseline	Small-Scale Intermodal Technology
CN Brampton	6,887	6,886
CN Malton	6,887	6,886
CN Mississauga	10,321	3,603
CP Vaughan	10,247	0
CP Windsor	0	1,080
CN Sudbury	0	2,112
CN Chatham	0	276
CN Hamilton	0	2,116
CN London	0	2,581
CP London	0	0
CP Hamilton	0	0
CP KWCG	0	1,449
CN Brockville	0	272
CN Ottawa	0	3,264
CN Kingston	0	1,237
CN St. Catharines	0	1,213
CP Peterborough	0	1,023
CN Sarnia	0	343
CP Sudbury	0	0

The logic for why the modelled output shows a move away from the existing Full-Scale Intermodal Terminals and to the Small-Scale Intermodal Technology Intermodal Service Sites is based capital costs and distance-related operational costs. The Open Solver linear optimization step of the model seeks to find an optimal solution that minimizes costs. As all of the existing Full-Scale Intermodal Terminals are located in the vicinity of Toronto it makes sense that the model would identify the regional smaller scale intermodal facilities that that are closer to the Ontario Economic Regions. The key variable for this is the reduced length of travel by road to the market which means reduced drayage costs. As the total rail operating cost is lower per distance travelled than the drayage cost this makes sense. It is noted that these figures do not include domestic intermodal flows which are sizeable between the west coast and Ontario. While two of the existing Greater Toronto Hamilton Area terminal see a modeled decrease in the Canada-US international containers it is likely that the domestic containers still provide substantial usage. For example, the CP Vaughan facility has a capacity in excess of 500,000 containers. With the Baseline Scenario estimating that Canada-US containers only account for just over 10,000 monthly containers it would seem plausible that the vast majority of containers handled at the existing full-scale intermodal terminals are domestic.

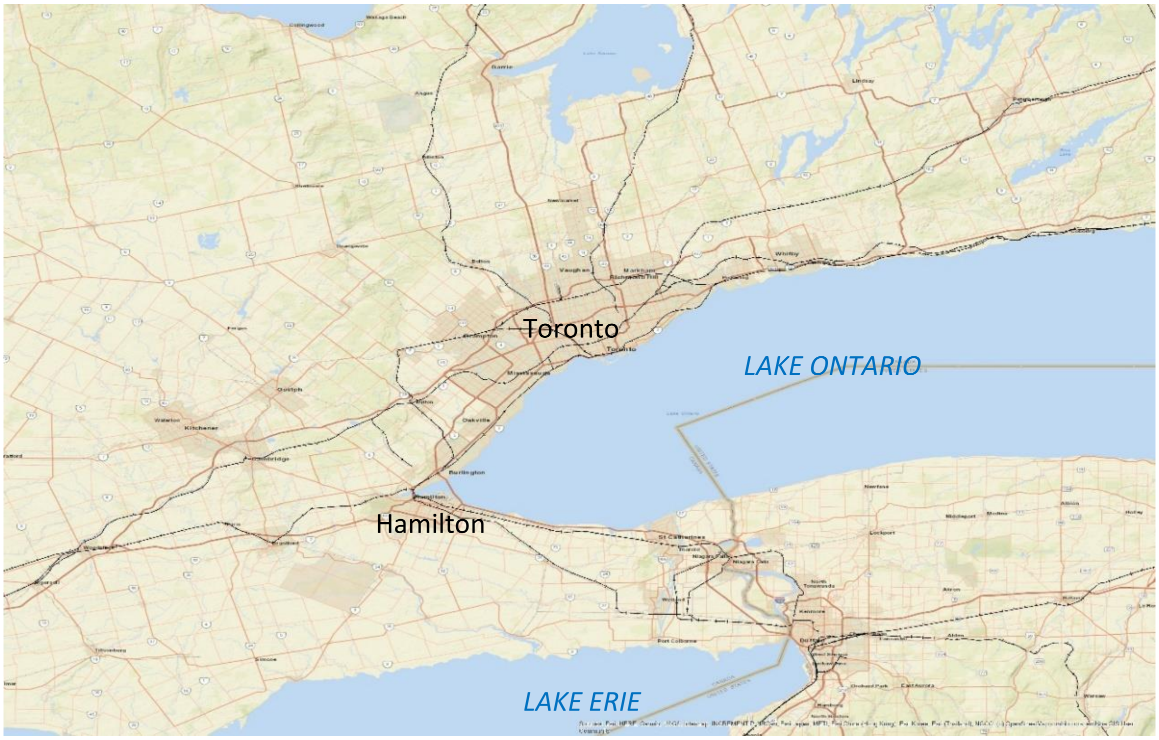

Figure 5.7 – Greater Toronto Hamilton Area of Southern Ontario

The results of the “Small-Scale Intermodal Technology Scenario” demonstrate that a Small-Scale Intermodal Technology such as Megaswing rail cars would benefit small and mid-sized communities in Ontario Economic Regions with shorter drays thus lower costs making economic development more attractive. From the opposite perspective, small-scale intermodal technology could result in some full-scale intermodal terminals becoming less viable as their service life increases with service providers needing to evaluate whether it is worth continuing to spend on operations, maintenance and potential replacement costs. The basis for this statement is the results demonstrated in Table 5.1, 5.2 and 5.3 show commodities would shipped to/from these Ontario Economic Regions and some of the commodities flows would shift away existing full-scale intermodal terminals. While this analysis only looks as the Canada-US rail trade, it seems reasonable that a similar trend could apply to domestic containers in the future. Through a general reduction in drayage costs there is potentially a benefit in the reduction in greenhouse gas emissions. The potential redevelopment of former rail yards is beyond the scope of this dissertation though has historically been an important policy issue for municipalities, notably the redevelopment of the former downtown Toronto Rail Lands, the Greber Plan to redevelop rail yards in the Ottawa and National Capital Region and the Windsor Non-Railway Uses of Railway Lands. This has implications for the results shown in Table 5.4, notably for Ottawa which would generate a number of cross-border container lifts approaching those observed at existing Toronto area facilities in the Baseline Scenario. The results in Table 5.4 demonstrate that these locations would be viable as small-scale intermodal terminals with the deployment of small-scale intermodal technology. If a modal shift from truck to rail for non-last mile cross-border commodity flows is considered as a result of environmental or climate change policy at the federal, provincial or municipal levels then it will be necessary to incorporate the land use planning process into the decision-making process to ensure that sufficient lands are available, designated and zoned for intermodal facilities.

This interpretation of the results shown in Table 5.4 leads to some interesting business-related questions about how would the implementation of small-scale intermodal technology be achieved and what would the implications on cross-border supply chains be? A typical freight rail car costs between $100,000 and $150,000 USD. Given that Megaswing technology is not typical, let’s assume that an average Megaswing rail car costs approximately $200,000 USD considering the specialty components and hydraulic systems. The actual cost of a Megaswing rail car has not been released in the public domain at the time of this writing. Given the capital expenditure required for a full-scale intermodal terminal, approximately $250 Million USD for a 400-acre facility, it would make sense for additional capacity in truck-rail intermodal to be achieved through small-scale intermodal technology. The exception being at locations that are also served by seaports where large gantry type cranes are the standard for moving containers between ships and truck or rail.

For comparison purposes, a railroad offering intermodal service could purchase a substantial fleet of Megaswing rail cars for the same capital cost as a full-scale intermodal terminal. Considering that existing full-scale intermodal terminals have operating and maintenance costs that are covered by fees charged to customers it would make economic sense to deploy small-scale technologies at a fraction of the cost to allow for increased intermodal service flexibility and to provide service to small-size and mid-size communities.

5.7 Conclusion

The analysis conducted in the “Small-Scale Intermodal Technology Scenario” demonstrates that a small-scale intermodal technology such as a Megaswing rail car would transform how commodities flow between cross-border origins and destinations in the context of the Ontario Economic Regions. This research contributes to the knowledge base about cross-border rail commodity flows in the North American context with emphasis on commodity flows to Ontario Economic Regions and represents the development of a novel approach to modelling commodity flows on the networks of Class I railroads in Canada and the United States.

A key limitation in this research is the GIS component of the model uses Dijkstra’s shortest path algorithm. While a reasonable approach for a preliminary model of this size and scope, the opportunity exists to develop and deploy a more realistic algorithm in the GIS environment for use with rail networks. As noted in this chapter there has been limited research published on cross-border rail commodity flows in the North American context and this research represents a beginning to serve as a foundation for future scholarly research. Opportunities exist to build and improve on the model used in this research and to explore data for other time periods and network scenarios. The network data set used in this research has been built so that it could be applied to future scenarios including microsimulation of flows in the system.

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CHAPTER 6

SUMMARY AND CONCLUSIONS

6.1 Fulfilled Objectives and Research Problems

This dissertation investigated modelling the North American Class I rail network in Canada and the United States to develop novel approaches for identifying feasibility of rail-truck intermodal facilities for cross-border commodity flows. As addressed in the literature review there has been a lack of research on modeling freight transportation in the North American context, and particularly in the Canada and United States cross-border commodity flow context. This dissertation represents a foundational study in the fields of modeling freight transportation in the North American context and modelling cross-border commodity flows by rail in the North American context. The research in this dissertation was focused around the following 4 objectives and 2 research problems:

Objective #1 is to describe the North American rail network, its history, how it works, connections, flows and the hierarchies of railroads within the Class I rail network. This objective was achieved in Chapter 2 of this dissertation.

Objective #2 is to understand why there is a knowledge gap in modelling rail commodity flows in the North American context. This objective was achieved in Chapter 3 of this dissertation. The knowledge gap exists because much of the rail commodity flow data is privately owned and there is little incentive for the private owners to make the data publicly available except in circumstances required by law or international agreement. Additionally, the size and complexity of the North American rail network poses a challenge for the development of modelling it as a system. This dissertation research represents a foundation for future North American rail network commodity flow research.

Objective #3 is to develop a scalable and adaptable multi-regional commodity flow model for use in the North American context. This objective was achieved in Chapters 3, 4 and 5 of this dissertation. A model was developed and successfully implemented in baseline, a full-scale intermodal and small-scale intermodal technology scenarios.

Objective #4 is the development of a scalable and adaptable North American Rail Network dataset for Canada and the United States. This objective was achieved in Chapter 3 of this dissertation. A North American Rail Network dataset for Canada and the United States was developed as a foundation for future research as part of this dissertation. The model can be scaled to examine smaller sub-regions of the Canada and the United States and can be adapted to add or remove terminals, junctions and segments of track as necessary for future research and analyses.

Research Problem #1 is to determine if a full-scale intermodal terminal would be used for cross-border container traffic if one was built in Windsor-Essex? This research problem was solved in Chapter 4 of this dissertation. The answer to the question is that if a full-scale intermodal terminal was built in Windsor-Essex it would be used and serve the Windsor-Essex, Chatham-Kent and Sarnia-Lambton markets, however the number of container lifts generated would not be sufficient to make a full-scale intermodal terminal economically viable.

Research Problem #2 is to determine if a small-scale intermodal technology were introduced into the North American Class I railroad system, would it be used for cross-border container traffic and would Windsor-Essex or other communities without full-scale intermodal terminals benefit from it? This research problem was solved in Chapter 5 of this dissertation. The answer is that introducing small-scale intermodal technology to the North American Class I railroad system would make sense as existing full-scale intermodal terminals reach the end of their service life or to expand intermodal services to locations where full-scale intermodal terminals would not be economically viable.

6.2 Contribution to the Research

6.2.1 Scalable Rail Network Dataset

This dissertation is the first research to develop a scalable rail network dataset suitable for modeling the complex North American cross-border commodity flows by rail in the Canada-US context.

6.2.2 Cross-Border Commodity Flows by Rail

Additionally, this dissertation marks the first research to model cross-border commodity flows by rail in the Canada-US context and look at full-scale intermodal terminals and small-scale rail-truck intermodal technology applications in the Canada-US context. These are substantial contributions to the research community because there is a relative lack of research on cross-border commodity flows in the North American context relative to the European and Asian contexts with a particular lack of research on North American cross-border freight transportation. The lack of research into cross-border freight transportation is surprising considering the value of trade between Canada and the US by rail (Aspila and Anderson, 2020) and the interdependencies of the Canadian and American economies with particular emphasis on trade between Ontario and American states bordering the Great Lakes (Anderson, 2012).

6.3 Policy Implications

6.3.1 Changes to Components of the North American Rail Network

Building on research presented in Chapters 3 and 4, the North American Rail Network dataset can be edited to add or remove features. This could include testing for impacts on commodity flows or the rail network if changes to the system were introduced. Examples could include the introduction of a new full-scale intermodal terminal at some location on the rail network, closure of a full-scale intermodal terminal, a merger or acquisition of one of the Class I railroads by another Class I railroad, closure of existing segments of the rail network, creation of new segments on the rail network, changes to the commodity flows across the rail network or adding the Mexican rail network to the Canada and United States portion of the North American Rail Network.

6.3.2 Small-Scale Technologies in Other Jurisdictions

Building on the research presented in Chapters 3 and 5, testing the impacts and viability of introducing small-scale technologies such as the Megaswing rail car to other jurisdictions or economic regions could be explored. As new technological innovations in the transportation industry are developed it is possible to test and estimate the impacts that these will have on the North American Rail Network.

6.4 Research Limitations

The research undertaken in this dissertation is intended to create a foundation for future research by the author and other academics because the knowledge base related to the research objectives and research problems is lacking in the North American and North American cross-border contexts. The available freight rail origin-destination data in the public domain is a limitation. Ideally, electronic waybill or freight-car specific GPS data would be used as a data source in this type of analysis, however this type of data is not available in the public domain as it is not in the railroad's competitive interests to release this data. If this data was available for research purposes it would allow for a very detailed examination of commodity flows, production patterns and consumption patterns considering data for both international and intranational routes. The best available alternative was to use province/state level flows for groups of commodities for the initial study.

The amount of data analyzed in this dissertation research was very large. The Canadian and American rail network data set includes over 12,900 segments and each segment contains many attributes. Given the size and detail of the rail network a basic network shortest path algorithm, the Dijkstra's algorithm deployed in ESRI's ArcGIS Network Analyst was used. This algorithm selects the shortest route segment out of the available options before proceeding to the next route segment. While this algorithm is well suited for short trips such as urban vehicle or pedestrian trips on public routes, it is not as well suited for modelling trips where the routing options are use of privately-owned rail lines with differing cost structures as is the case with then North American Class I rail network. In the case of privately owned rail networks, there is opportunity to explore development of custom-designed network shortest path algorithms to better represent optimized cost routings than those generated based on the Dijkstra algorithm.

Building on the data quality issue discussed above, better data availability and better Canadian data availability would allow for better analyses of the impacts of new technologies on the delivery of rail and intermodal rail-truck services. The issue of protecting competitive business interests directly conflicts with the ease of conducting meaningful research in the North American rail sector. While this is less of an issue in the European, Asian and African contexts where many rail networks are government owned and also more commonly government operated, private ownership of the networks presents a substantial disincentive to allow for public research in the North American context.

6.5 Extensions of this Research

As the research in this dissertation serves as a foundation for future research about rail, rail truck-intermodal and cross-border multi-regional commodity flows, there are many opportunities to extend this research. By achieving Objectives #1, #2, #3 and #4 this research serves as a foundation for further research to be built upon as there is a gap in the knowledge base about multi-regional commodity flow modelling in the North American context. In this dissertation, the month of June was selected as it has historically been the busiest month for North American rail transportation and the year of 2017 was selected because it was the most recent year where both commodity flow data and cost data were available. Opportunities exist to explore spatial and temporal changes in the commodity flows by preparing and analyzing data for other months and years where existing data is available and for future years as new data is released by government sources.

6.5.1 Development of New Algorithms and Sub-Models

There are opportunities to develop new algorithms and sub-models to expand on the model developed in this dissertation research. These opportunities include adding production and consumption data to the model as well as adding other modes of intermodal transport such as sea transport, pipeline transport and air transport to the model. Opportunities also exist to create sub-models with specific model parameters for individual political jurisdictions, railroads or transportation modes.

6.5.2 Automation of Model Components

This dissertation research included the development of a new model that was manually implemented with the exception of partial automation of transferring output data from the Stage 1 GIS-based network analysis to the Stage 2 OpenSolver-linear optimization analysis. Development, testing and implementation of the model was a very user-intensive and time-intensive exercise. Now that the model has been created and implemented there is opportunity to automate the GIS data preparation, GIS network analysis, OpenSolver data preparation and OpenSolver analysis components for the purpose of a more user-friendly and efficient to use modelling toolset.

6.5.3 Modelling Rail in the Domestic Context

There is opportunity to build on the Canada-USA cross-border approach taken in this dissertation research and to look at commodities flows by rail within Canada or the United States. Should data become available for research purposes in the future it would be interesting to examine commodity flows in the domestic context for the countries as these likely differ from the cross-border context. While beyond the scope of this foundational research, a comprehensive analysis of these aspects of rail commodity flows would benefit future cross-border rail research by providing a more fulsome understanding of how rail networks are used both domestically and internationally within Canada and the USA.

6.5.4 Small-Scale Intermodal

There is potential to examine small scale intermodal in the North American context. Although more widely accepted in Europe with scheduled, higher-frequency short intermodal trains, this has not been investigated for opportunities within Canada and the USA. One of the areas that could be specifically examined is consideration of handling time for small scale intermodal and whether it would make sense for the shippers, the railroads and the trucking companies.

6.5.5 Green House Gas Generation and Climate Change Implications

It is generally accepted that almost all national governments around the world have acknowledged that climate change has reached a crisis-level that will have serious implications for life on Earth. European governments have set aggressive targets to reduce atmospheric pollution generated in their jurisdictions including those resulting from diesel exhaust. With aggressive timelines and targets in place this has led to intermodal becoming a preferred option in Europe as it results in fewer greenhouse gasses generated compared to shipping point to point by unimodal truck. The opportunity to examine the climate impacts of using rail-truck intermodal instead of truck-unimodal exists as the US Environmental Protection Agency has established standards for exhaust generation including the use of tiers that must be met for railroad locomotives to be operated. There is opportunity to explore the climate change implications of rail intermodal including modal shift towards rail in the North American context.

6.6 Final Remarks

This dissertation research represents a foundational study that serves as a base for future research in modelling cross-border commodity flows by rail in the North American context, the study of cross-border intermodal commodity flows, and the development of modelling techniques for the rail sector. The products of this research are a scalable and adaptable rail network model of the Canada and United States portion of the North American Rail Network, a multi-regional network commodity flow model, an example of implementing the model to examine viability of developing a new full-scale intermodal terminal at a location on a rail network, and exploring the viability of implementing a real-world small-scale intermodal technology on a rail network and identifying whether communities that are served or not served by rail would benefit from the small-scale intermodal technology being implemented. The key recommendation from this dissertation is that small-scale intermodal technology should be deployed as it becomes available to serve Ontario Economic Regions for cross-border commodity flows. The research is novel and demonstrates the potential for future research in these topical areas for the solving of real-world transportation planning and transportation engineering problems.

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APPENDICES

Appendix ‘A’ – Summary of Variables Used in the Model

Variable Name	**Field Name**	**Source**
Name of Origin / Destination Terminal	JNAME	ORNL
Distance	Miles	ORNL
Track Speed Limit	EMLC	ORNL
Number of Mainline Tracks	TRKTYP	ORNL
Primary Track Owner	W1	ORNL
Secondary Track Owner	W2	ORNL
Trackage Rights #1	T1	ORNL
Trackage Rights #2	T2	ORNL
Trackage Rights #3	T3	ORNL
End of Mainline	End	Future Use - New field manually edited by author
Track Segment Travel Time	FT_Minutes / TF_Minutes	New fields calculated by: Miles / EMLC * 60
Directional From End	F_End	Future Use - New field manually edited by author
Directional To End	T_End	Future Use - New field manually edited by author
Origin (Boolean)	Origin	New field manually edited by author to represent the amount of commodity (USD value) originating at origin i
Destination (Boolean)	Destination	New field manually edited by author to represent the amount of commodity (USD value) terminating at destination j
Boolean Include Origin/Destination	DesOD	New field manually edited by author to represent the whether a intermodal terminal is an origin or destination for commodity r.
Unit Cost Per Ton	UnitCostTn	New field containing URCS data manually edited by author

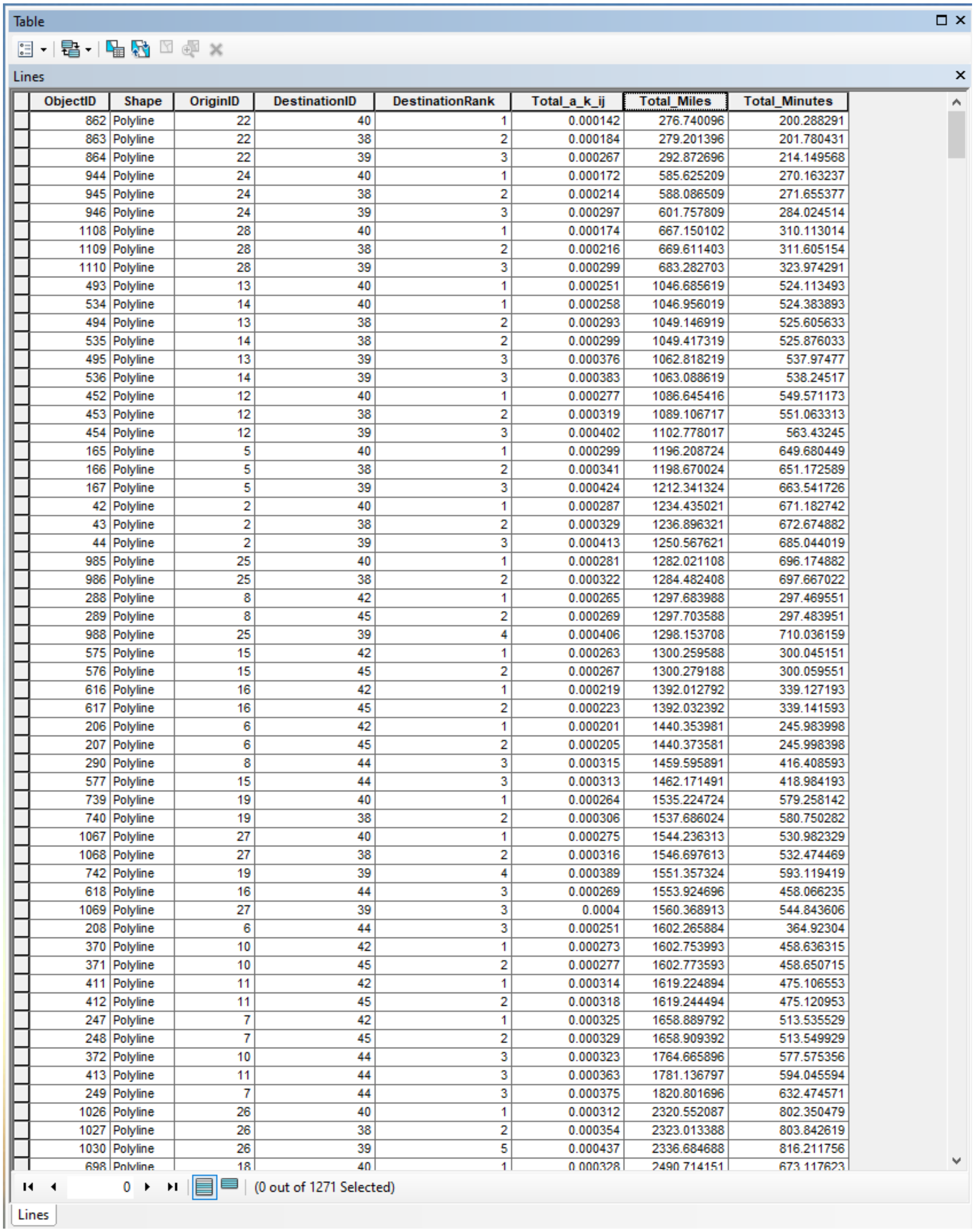
Shipping Cost Per Ton by BTS Commodity Group from Canada to US	CU####	New series of fields where #### represents the BTS commodity groups. Manually edited and added to DesOD by author
Shipping Cost Per Ton by BTS Commodity Group from US to Canada	UC####	New series of fields where #### represents the BTS commodity groups. Manually edited and added to DesOD by author
Estimated Proportionate Percentage of Commodity by Dollar Value per Terminal for Province/State	PR_ST_Wt	New field containing an estimate of the proportionate percentage of commodity by dollar value per terminal
Amount of commodity r to be exported from terminal i	E_r_i	Cost per lb / 1,000
Amount of commodity r to be imported through terminal i;	I_r_i	Cost per lb / 1,000
Amount of commodity r shipped from terminal i	X_r_i	Summed using Network Analyst output DBase IV table values in Linear Optimization Spreadsheet
Amount of commodity r shipped from terminal i to terminal j by mode k	X_rk_ij	Summed using Network Analyst output DBase IV table values in Linear Optimization Spreadsheet
Optimum expansion of terminal i	H_r_i	Optimized in Linear Optimization Spreadsheet
Amount of commodity r that is to be handled within Existing capacity of terminal i. Once the throughput volume reaches Q_i^r, maximum capacity of terminal i, the model will suggest optimum expansion of terminal i (H_i^r)	Hbar_r_i	Optimized in Linear Optimization Spreadsheet
Excessive amount of commodity that cannot be handled with the existing capacity of system k for shipping them from terminal i to terminal j.	T_k_ij	For future use. To be calculated as a Decision Variable in Linear Optimization Spreadsheet

The amount suggests, if positive, optimum expansion of system *k* between termnals *i* and *j*		
Total amount of commodity shipped between regions *i* and *j* that is within shipment capacity of system *k* between regions *i* and *j*. Once the maximum capacity is reached (expressed by $\overline{L}_{ij}^{k}$), the model will suggest optimum expansion of system *k* between regions *i* and *j*	Tbar_k_ij	Optimized in Linear Optimation Spreadsheet
User cost for shipping unit amount of commodity between terminals *i* and *j* using system k. Unit user cost, $ / ton / km ($ is US dollars)	a_k_ij	Summed in Network Analysis for each route and used as an input variable in the Linear Optimization Spreadsheet.
Annual equivalent construction cost (assuming 10 years or 120 months of durable life years / track km and 20 years or 240 months of durable life years / intermodal facility infrastructure and equipment)	b_k_ij	Summed in Network Analysis for each route and used as an input variable in the Linear Optimization Spreadsheet.
Handling cost (user cost per unit amount of commodity *r* at terminal *i* excluding any off-terminal drayage costs to other sites	d_r_i	New field based on URCS data manually entered by author.
Annual equivalent construction cost for handling unit excess amount of commodity *r* at terminal *i*	_e_r_i	Calculated in Linear Optimization Spreadsheet.
Handling capacity of terminal *i* per year	Q__i	Estimated the number of 60-foot intermodal rail cars the terminal could handle based on observed ratios of

		length of yard track to terminal size.
Monthly throughput capacity of system *k* per track in tonnage	q_k	Estimated based on TRKTYP * Tons
Recommended expansion of existing tracks for system *k* between regions *i* and *j*	L_k_ij	Could be calculated in Linear Optimization Spreadsheet using US dollar equivalent.
Number of existing tracks for system *k* between regions *i* and *j*	Lbar_k_ij	Future Use - decision variable optimized using US dollar equivalent in the Linear Optimization Spreadsheet
Segment Cost per Ton	SegCostTn	Summed in Network Analysis.
60-foot equivalent freight car capacity	60ftCap	Estimated based on the length of track divided by 60 feet (converted from feet to miles) .
Cost per Container Lift	CostCLift	Based on URCS data entered by author.
Tons	Tons	Calculated by dividing total value of commodity by the cost per ton of the commodity.
Measured Size of Terminal Facility	Acres	Measured using ArcGIS.
Drayage Cost to transport from the terminal *i* to or from destination *j* excluding any on terminal handling costs including in d_r_i	_d_k_ij	Multiplied 2017 trucking cost by distance from the regional centre to/from the destination.
Distance from the regional centre	Dis_YYZ	Measured using ArcGIS.
Total Cost	Cost	Future Use - Summed using ArcGIS.
Subtotal Cost Excluding Terminal Cost	CostNoPort	Future Use - Summed using ArcGIS.
Subtotal Terminal Cost	PortCost	Future Use - Summed using ArcGIS.
Hierarchy Score for BNSF	Hier_BNSF	Estimated by the author based on published information by the Class I railroads.

Hierarchy Score for CN	Hier_CN	Estimated by the author based on published information by the Class I railroads.
Hierarchy Score for CP	Hier_CP	Estimated by the author based on published information by the Class I railroads.
Hierarchy Score for CSXT	Hier_CSXT	Estimated by the author based on published information by the Class I railroads.
Hierarchy Score for KCS	Hier_KCS	Estimated by the author based on published information by the Class I railroads.
Hierarchy Score for NS	Hier_NS	Estimated by the author based on published information by the Class I railroads.
Hierarchy Score for UP	Hier_UP	Estimated by the author based on published information by the Class I railroads.

Appendix ‘B’ – Sample ArcGIS Network Analyst Output Table



ObjectID	Shape	OriginID	DestinationID	DestinationRank	Total_a_k_ij	Total_Miles	Total_Minutes
862	Polyline	22	40	1	0.000142	276.740096	200.288291
863	Polyline	22	38	2	0.000184	279.201396	201.780431
864	Polyline	22	39	3	0.000267	292.872696	214.149568
944	Polyline	24	40	1	0.000172	585.625209	270.163237
945	Polyline	24	38	2	0.000214	588.086509	271.655377
946	Polyline	24	39	3	0.000297	601.757809	284.024514
1108	Polyline	28	40	1	0.000174	667.150102	310.113014
1109	Polyline	28	38	2	0.000216	669.611403	311.605154
1110	Polyline	28	39	3	0.000299	683.282703	323.974291
493	Polyline	13	40	1	0.000251	1046.685619	524.113493
534	Polyline	14	40	1	0.000258	1046.956019	524.383893
494	Polyline	13	38	2	0.000293	1049.146919	525.605633
535	Polyline	14	38	2	0.000299	1049.417319	525.876033
495	Polyline	13	39	3	0.000376	1062.818219	537.97477
536	Polyline	14	39	3	0.000383	1063.088619	538.24517
452	Polyline	12	40	1	0.000277	1086.645416	549.571173
453	Polyline	12	38	2	0.000319	1089.106717	551.063313
454	Polyline	12	39	3	0.000402	1102.778017	563.43245
165	Polyline	5	40	1	0.000299	1196.208724	649.680449
166	Polyline	5	38	2	0.000341	1198.670024	651.172589
167	Polyline	5	39	3	0.000424	1212.341324	663.541726
42	Polyline	2	40	1	0.000287	1234.435021	671.182742
43	Polyline	2	38	2	0.000329	1236.896321	672.674882
44	Polyline	2	39	3	0.000413	1250.567621	685.044019
985	Polyline	25	40	1	0.000281	1282.021108	696.174882
986	Polyline	25	38	2	0.000322	1284.482408	697.667022
288	Polyline	8	42	1	0.000265	1297.683988	297.469551
289	Polyline	8	45	2	0.000269	1297.703588	297.483951
988	Polyline	25	39	4	0.000406	1298.153708	710.036159
575	Polyline	15	42	1	0.000263	1300.259588	300.045151
576	Polyline	15	45	2	0.000267	1300.279188	300.059551
616	Polyline	16	42	1	0.000219	1392.012792	339.127193
617	Polyline	16	45	2	0.000223	1392.032392	339.141593
206	Polyline	6	42	1	0.000201	1440.353981	245.983998
207	Polyline	6	45	2	0.000205	1440.373581	245.998398
290	Polyline	8	44	3	0.000315	1459.595891	416.408593
577	Polyline	15	44	3	0.000313	1462.171491	418.984193
739	Polyline	19	40	1	0.000264	1535.224724	579.258142
740	Polyline	19	38	2	0.000306	1537.686024	580.750282
1067	Polyline	27	40	1	0.000275	1544.236313	530.982329
1068	Polyline	27	38	2	0.000316	1546.697613	532.474469
742	Polyline	19	39	4	0.000389	1551.357324	593.119419
618	Polyline	16	44	3	0.000269	1553.924696	458.066235
1069	Polyline	27	39	3	0.0004	1560.368913	544.843606
208	Polyline	6	44	3	0.000251	1602.265884	364.92304
370	Polyline	10	42	1	0.000273	1602.753993	458.636315
371	Polyline	10	45	2	0.000277	1602.773593	458.650715
411	Polyline	11	42	1	0.000314	1619.224894	475.106553
412	Polyline	11	45	2	0.000318	1619.244494	475.120953
247	Polyline	7	42	1	0.000325	1658.889792	513.535529
248	Polyline	7	45	2	0.000329	1658.909392	513.549929
372	Polyline	10	44	3	0.000323	1764.665896	577.575356
413	Polyline	11	44	3	0.000363	1781.136797	594.045594
249	Polyline	7	44	3	0.000375	1820.801696	632.474571
1026	Polyline	26	40	1	0.000312	2320.552087	802.350479
1027	Polyline	26	38	2	0.000354	2323.013388	803.842619
1030	Polyline	26	39	5	0.000437	2336.684688	816.211756
698	Polyline	18	40	1	0.000328	2490.714151	673.117623

0 (0 out of 1271 Selected)

Appendix ‘C’

For exogenous variable a_{ij}^{k}, representing the user cost in USD to ship a unit of commodity between terminals *i* and *j* using system *k*, a matrix with the rows representing the number of origins *i* and the columns representing the number of destinations *j* with the cells of the matrix representing the corresponding value of a_{ij}^{k}.

For exogenous variable y_{ik}^{r}, representing the drayage cost between the terminal *i* and regional centre *k*, a matrix representing the number of origins *i* and the columns representing the number of destinations *j* with the cells of the matrix representing the corresponding value of y_{ik}^{r}.

For endogenous variable X_{ij}^{r}, representing the amount of each commodity *r* shipped between terminals *i* and *j* (estimated using a doubly constrained gravity model)..

Endogenous variable H_{i}^{r}, representing the amount of commodity *r* that is to be handled with the existing capacity of terminal *i* is shown in a column.

Exogenous variable d_{i}^{r}, representing the handling cost per unit amount of commodity *r* at terminal *i* is shown in a column.

Exogenous variable e_{i}^{r}, representing the annual equivalent construction cost for handling excess amount of commodity *r* at terminal *i* is shown in a column.

Decision variable EH_{i}^{r}, representing the excessive amount of commodity *r* that cannot be handled within the existing capacity of terminal *i* and therefore the optimum expansion of terminal *i* for handling commodity *r* is calculated by the optimization and the solution is displayed in a column.

Exogenous variable Q_i^r, representing the handling capacity of terminal i for each commodity *r* is displayed in a column.

Endogenous variable E_i^r, representing the amount of commodity *r* exported through terminal *i* is displayed in a column.

Endogenous variable I_i^r, representing the amount of commodity *r* imported through terminal *i* is displayed in a column.

Constraint 1, $E_i^r + I_i^r \le H_i^r,\ \forall\, r$ and i, is represented in a pair of columns.

Constraint 2, $\sum_r H_i^r \le Q_i, \forall\, i$, is represented in a pair of columns.

Constraint 3, $\sum_r X_{ij}^r \le T_{ij}, \forall\ \ i$ and *j*, is represented as a pair of matrices, the first for the left side of the inequality, the second for the right side of the inequality, where the rows represent the amount of commodity *r* exported through terminal *i*, and the columns represent the amount of commodity *r* imported through terminal *j*.

Constraint 4, $\sum_k G_{ik}^r \le H_i^r + EH_i^r,\ \forall\, r,\ i\ and\ k,$ is represented by summing the rows of the G_{ik}^r matrix.

Constraint 5, $\sum_i \sum_r G_{ik}^r = D_k,\ \forall\, r,\ i\ and\ k,$ is represented by summing the columns of the G_{ik}^r matrix.

Decision variable T_{ij} , representing the total amount of commodities shipped between terminals *i* and *j* is calculated by the optimization and the solution is displayed in a matrix with the rows representing the amount of commodities exported through terminal *i* and the columns representing the amount of commodities imported through terminal *j*.

The objective function is expressed with the sum of three terms, the first being the calculation of total existing optimized costs in the system, the second being the calculation of total optimized intermodal terminal costs and the third being the calculation of drayage from intermodal terminals to Ontario Economic Regions.

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