Assessing the Cost Competitiveness of a Cargo Airship for Freight Re-Supply in Isolated Regions in Northern Canada

by

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Abstract

Many regions in northern Canada lack access to all-season road infrastructure. As a result, the transportation systems serving these regions are high-cost, unreliable, and service levels vary seasonally. The lack of low-cost, reliable freight transport service year-round imposes myriad negative impacts on these region's residents. Improving freight transportation service in northern Canada using existing freight transportation technologies is cost-prohibitive. The cargo airship has been advanced as a solution, and the purpose of this research is to evaluate the cost competitiveness of this emerging mode of transportation to serve isolated northern communities.

The East Side of Lake Winnipeg, North Western Ontario, and the Kivalliq region in Central Nunavut are selected as case regions in which the cost competitiveness of the cargo airship can be estimated. Data from the North West Company that describes freight movements and associated costs are used in this comparative analysis. A cargo airship developer provided operating cost data that are operationalized using the North West Company's freight shipments.

Results from the case analyses show that using a cargo airship could produce annual transportation cost savings of between 12.5% and 38.3% per year. These results are similar across all three regions and vary based on the scenario modelled within each case region. The findings from this research are subject to the assumptions that the operating cost model described by the cargo airship developer is accurate, and is limited in scope because it focuses solely on one company's shipping needs in select regions.

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Table of Contents

List of Tables

List of Figures

List of Equations

Chapter 1: Introduction, Research Purpose, and Methodology

1.1 Introduction

The purpose of this thesis is to quantitatively assess the operating cost performance of cargo airships serving isolated northern Canadian regions. The term isolated is defined as a lack of all-season road access. This thesis tests whether or not the cargo airship possesses a relative economic advantage using data that describe actual northern freight flows and a proposed cargo airship design.

Setting the stage for the cost analysis is an investigation into why a technological solution is needed for improving freight transportation service levels in northern Canada. Cargo airships have been advanced as a solution to northern transportation problems but minimal research into their relative economic advantage has been conducted. This thesis also addresses gaps in the literature on northern freight transportation systems and stakeholder dynamics in the development and diffusion of new technologies.

This thesis is composed of three intertwined research components. Different methodological approaches are employed for describing the northern freight transportation problem, for addressing the impediments to cargo airship development and establishing the need for quantitative economic performance of this potential new mode of transportation. This introductory chapter describes the research design for each of these three components, as well as the overall structure of the thesis.

1.2 Describing the Northern Freight Transportation Problem

The purpose of this research component is to describe the general nature of the northern Canadian freight transportation problem. Research into the economic performance of a technological solution first requires an in-depth understanding of the underlying problem it is designed to solve. Research attention is devoted to this topic for two reasons. The first is to serve the immediate needs of this thesis in justifying the evaluation of new transportation technologies for northern applications. The second is to establish an academic record on this topic to serve as a reference for future research endeavours.

A paucity of academic research exists on northern freight transportation systems and their impacts on the communities they serve. There is interplay between a social system, such as a community or region, and the transportation service available to it (Manheim, 1979). The research conducted in chapter two focuses on the transportation systems that serve isolated regions in northern Canada, how the performance of these transportation systems impact the residents of these regions, and the challenge of improving service levels given the long distances and terrain typically found in northern Canada. Guiding this exploratory research are the following research questions:

RQ1a: What modes of freight transportation are available in isolated regions?

RQ1b: What is the level of performance of the freight transportation systems serving isolated regions in terms of cost and reliability?

RQ1c: What are the transportation-related impacts on residents of isolated regions?

RQ1d: What challenges arise when attempting to improve service levels in isolated regions?

A qualitative case study approach is employed because it allows for an in-depth investigation of a construct based on the synthesis of a wide range of data sources (Yin, 2009). Moreover, a single-case method is employed because the quantity of data required for this research was available for only the East-Side of Lake Winnipeg (ESLW) region in Manitoba. This region's freight transportation challenges have received significant attention recently from several government agencies and the news media. Although the details may differ, the challenges this region faces are likely to be generally similar to those experienced in other isolated regions. Therefore, the ESLW region is used as a representative case (Yin, 2009) for describing the general characteristics of northern transportation systems, the consequences they impose on communities in isolated regions, and the challenges that arise from attempting to improve freight transportation service levels.

Data for this study are gathered from secondary sources including government reports, newspaper articles, conference proceedings, and other non-academic sources. Peer-reviewed data sources could not be found despite an exhaustive literature search.

The reliance on secondary sources means one of the possible limitations of this research is reporting bias (Yin, 2009). The single-case design is necessary because of limited data availability. It is expected that the generalities of the transportation-related problems experienced in the ESLW would be similar in other isolated regions in northern Canada.

1.3 The Role of Performance Information in Innovation Development and Diffusion

The cargo airship has been advanced as a solution to freight transportation problems in isolated regions yet no concrete information exists about its economic performance in this role. This in part explains the lack of business confidence in cargo airships (Prentice & Russel, 2009). Neither government nor commercial stakeholders in Canada are willing to commit the resources and create the regulatory environment necessary for the technology's development (Standing Committee on Transport, Infrastructure and Communities, 2013). These stakeholders are unlikely to engage without concrete information about the cargo airship's performance.

The objectives of this chapter are to understand the role of information in innovation development and diffusion processes. This research required an extensive review of literature on innovation diffusion, innovation development, and stakeholder involvement in these processes. The literature review, found in appendix A, reveals that the development and diffusion of innovations are susceptible to the actions of multiple stakeholders, and that certain stakeholders have the power to disrupt an innovation's development or diffusion at various times along its lifecycle. For the purposes of this thesis the focus is on the role of information in innovation development and diffusion processes.

The need for this research is twofold. First, it emphasizes the need for information about the economic performance of a proposed cargo airship design. Second, no cargo airship has ever entered into operational service despite sporadic development projects since at least the 1950's (Aereon Corporation, 2004). It is necessary to understand the barriers that impede the commercialization of this technology and how these impediments can be overcome with cargo airship economic performance information. The following research questions guided this research:

RQ2a: What are the innovation characteristics of the cargo airship?

RQ2b: What contextual factors impede the cargo airship's adoption?

RQ2c: What role does performance information play in reducing the barriers to the cargo airship's diffusion?

1.4 Assessing the Economic Performance of the Cargo Airship

The purpose of this research component is to assess the economic performance of a proposed cargo airship design relative to existing modes of transportation serving isolated regions in northern Canada. Previous attempts to quantify the relative economic performance of cargo airships have shown they are cost-competitive in certain circumstances (Prentice & Thomson, 2004; Prentice, B.E., & Thomson, J., 2003) and not in others (Larson, 2009). Otherwise, research on cargo airships concentrates on specific applications for the technology, on requirements for their operation, and on their viability as a transportation technology (Prentice, Beilock, & Phillips, 2004; Prentice & Russell, 2009; Prentice & Thomson, 2003; Prentice, B. E, & Thomson, 2004; Sherwood & Prentice, 2010; Prentice et al., 2013).There remains a need to assess the cargo airship's economic performance using data that describes actual freight flows and transportation costs in northern isolated regions.

No published data are available on northern freight flows and associated transportation costs or cargo airship operating costs. The major contributions of this thesis are derived from this third research component because it addresses these research gaps and provides insight into whether or not cargo airships are a low-cost alternative to existing modes of freight transportation. Three research questions guide this research:

RQ3a: What are the freight flows and transportation costs in isolated northern regions?

RQ3b: What is the cost of operating a modern cargo airship?

RQ3c: What is the difference in cost between the cargo airship and existing modes of transport?

This research component is the most complex of the three, and is therefore divided into three sub-sections. The first section provides descriptions and of the cargo airship operating cost model. The second section includes an analysis of existing freight transportation flows in isolated regions in northern Canada based on the shipper's data. Freight flows are described in terms of origin and destination pairs, freight types and quantities, and associated transportation costs. Finally, the third section presents the results from eight scenarios used to simulate the cost performance of a proposed cargo airship design.

The methodology employed in this research component is a multi-case methodology with a theoretical replication approach (Yin, 2009). Each case represents an isolated region in Canada, and the unit of analysis in each case is its freight transportation system. The three cases differ in terms of land area, freight quantity and mix, and modal split. Evaluation of the cargo airship's cost performance occurs within cases and between cases. The within-cases analyses reveal whether or not the cargo airship is a low-cost alternative to existing modes of freight transportation. The between-case analyses permit the formulation of theoretical propositions about the cargo airship's cost behaviour. The main measurement is *D*, the proportional cost differential between the cargo airship freight transportation systems and the baseline systems.

The data used in this component are sourced from industry experts[1]. Shippers and cargo airship developers were contacted purposively due to their area of expertise. The shipper's datasets describe actual freight transportation operations across Canada over a one year period. The cargo airship developer's operating cost data were operationalized in a spreadsheet operating cost model. The cost factors in this spreadsheet are based on best estimates because this cargo airship design is still in its early stages of development. Nonetheless, this cost model is the best available for this research.

The limitations of this research relate to issues of scope. Generalizability to the cargo airship's cost performance is limited because climate is not included in the scenario analyses. Incorporating accurate climate effects into the cost model is impossible for this

[1] This research was conducted after a review by the Research Ethics and Compliance office at the University of Manitoba (Protocal #J2012:212).

study but would be worthwhile in future research. In addition, limiting the geographic scope to the Canadian context limits the generalizability to other countries or regions. The relative cost performance of the cargo airship depends on the costs of available modes of transportation. These costs may be higher or lower in other regions therefore more research in other geographic areas would also be worthwhile.

1.7 Thesis Structure

The preceding sections describe each research component of this thesis. The case study on the ESLW and its freight transportation system is included in the following chapter. Chapter three includes the research on innovation management and cargo airship development. The remaining chapters of this thesis are devoted to the third research component. Chapter four includes an introduction to the shipper, describes the case selection process, and a review of the cargo airship operating cost model. The case studies for each of three regions included in the cost comparison analysis are found in chapters five, six, and seven. A description of each case region and cargo airship alternative, along with the results from each analysis, are found in each case chapter. A comparison of results across regions is found in chapter nine. Discussion of the results are found in chapter ten, and recommendations for future research follow in chapter ten.

Chapter 2: The Northern Transportation Problem

"Large parts of the Third World are characterised by lack of year-round mechanised transport and movement is by unreliable, high-cost, labour-intensive methods."

– David Hilling (Hilling, 1996)

"While other Canadians experience improvements in their quality of lives, many First Nation communities live in conditions that rival third-world countries."

– Sheila Fraser, former Auditor General (ISIS Research Centre, 2011)

2.1 Introduction

The adoption of rail technology in Canada during the 19th century was transformative for the nation. The construction of railways across the country created myriad economic opportunities and allowed political consolidation from east to west (Library and Archives Canada, 2003). The challenge of providing infrastructure-based transportation service to a small population spread over a large land area led to severe financial consequences both for the railway companies (Library and Archives Canada, 2003) and for the government (Prentice & Thomson, 2003). The imperative is now to achieve a greater degree of connectivity to Canada's north. The following discussion illustrates how, given the geographic characteristics of isolated regions and existing transportation technologies, achieving greater north-south connectivity will come at a high economic cost.

The ESLW region serves as a representative case to describe the interaction between northern transportation systems and the regions they serve. Chapter two is organized as follows. A background on the ESLW is presented in the next section. The two sections thereafter describe the region's freight transportation system. Transportation-related impacts are discussed thereafter, and this is followed by a description of the East

Side Road (ESR). The concluding section provides a discussion of how the findings from the ESLW case can be generalized to other isolated regions in northern Canada.

2.2 Background

The provision of freight transportation service is a challenge in the remote, isolated northern communities in Canada. The ESLW is one such region. The region is bordered by Lake Winnipeg to the west, the Ontario border on the east, Oxford House in the north, and Bloodvein in the south (Buhr, Krahn, & Westdal, 2000). It possesses a small population dispersed over a relatively large land area, and lacks all-season road infrastructure. Figure 1 is a map of the region that shows the approximate location of the region and its communities.

Map Marker Legend:

1. Oxford House
2. God's River
3. God's Narrows
4. Red Sucker Lake
5. Island Lake/Garden Hill
6. Wasagamack
7. St Theresa Point
8. Pauingassi
9. Little Grand Rapids
10. Bloodvein
11. Berens River
12. Poplar River

Figure 1 - Map of the ESLW region and the approximate geographic location of its communities. *Modified from*: Canada – Prairie Provinces [computer file]. (no date). St. Catherines, Ontario: Brock University Map Library. Available: Brock University Library Controlled Access http://www.brocku.ca/maplibrary/maps/outline/North_America/PRARIES.pdf. Brock University provides this and other maps for free use by the public.

The twelve First Nations communities in the region are home to a population of 13,249 (Manitoba Bureau of Statistics, 2008). Table 1 lists the ESLW communities and their population. Although the average population density of the twelve community centres is 42 persons per square kilometer (Manitoba Bureau of Statistics, 2008), the population density of the entire region is less than one person per square kilometre (Natural Resources Canada, 2009). The difference between the two figures highlights the size of the region relative to the size of its population.

Table 1 - Population of ESLW by community (Manitoba Bureau of Statistics, 2008)

Community	Population	Community	Population
Bloodvein	576	Wasagamack	1,160
Berens River	739	Garden Hill/Island Lake	1,898
Poplar River	643	Red Sucker Lake	845
Little Grand Rapids	796	Oxford House	1,947
Pauingassi	352	Gods Narrows	1,105
St. Theresa Point	2,632	Gods River	556
		Total	13,249

Communities located in the north and with small populations are not necessarily isolated. The City of Thompson, Manitoba is located further north than the ESLW region but is connected to the provincial highway and rail network. So are other northern communities in Manitoba like Flin Flon and Snow Lake. As of 2006, the populations of these communities were 13,446, 5,594, and 837 respectively (Manitoba Bureau of Statistics, 2008). Large mineral deposits in and around these communities created an impetus to connect them to surface transportation networks. By comparison, there is scant economic activity in the ESLW region. Commercial activity in the region is limited to forestry, trapping, commercial fishing, hunting, and sport fishing (Manitoba Conservation).

2.3 Freight Flows – Modal Choice and Availability

Freight transportation service in the ESLW is limited by the region's lack of permanent road infrastructure. Freight is transported into the region predominantly by trucks over winter roads and by air (Buhr, Krahn, & Westdal, 2000). In addition, three communities are accessible by barge. Figure 2 illustrates the proportion of freight tonnage transported by each of the available modes into communities with and without access to barge service.

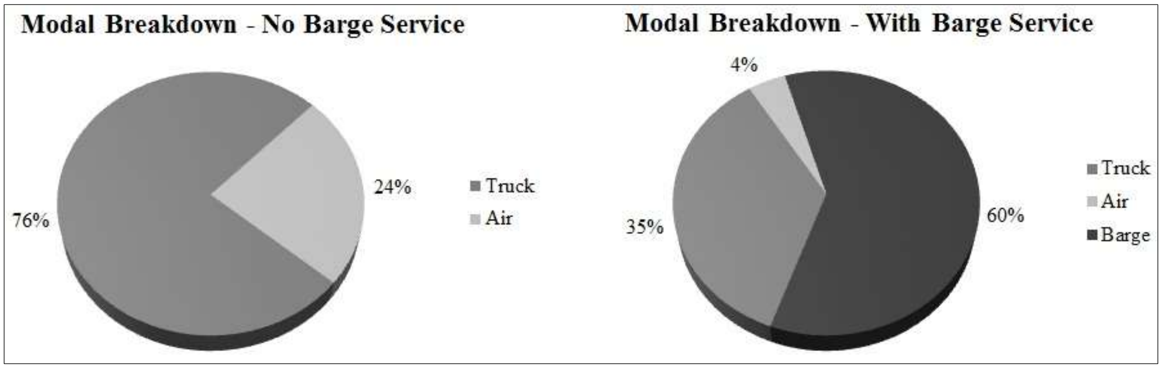

Figure 2 - Freight tonnage by mode in ESLW communities with/without barge service. Source: (Buhr, Krahn, & Westdal, 2000).

Although shippers rely heavily on surface modes of transportation, modal choice is dictated by modal availability. Air is used more extensively in communities without access to barge service. Barge service is used extensively where it is available however 85% of the ESLW population lacks access to it[2]. Although the winter road season is limited to at most approximately 50 days per year (Kuryk, 2003a), 69% of the total freight tonnage transported into the ESLW region is carried by truck (Buhr, Krahn, & Westdal, 2000). Shippers schedule the majority of their freight shipments during the winter road season in order to minimize freight costs (Manitoba Aboriginal and Northern Affairs, 2003). The figures presented above illustrate that the ability of shippers to minimize freight costs is constrained by modal availability.

[2] Barge service is available in Bloodvein, Berens River, and Poplar River (Buhr, Krahn, & Westdal, 2000, 5-11).

2.4 The ESLW Freight Transportation System Performance

The cost performance of the ESLW's freight transportation system is low. Compared to average trucking rates, winter road trucking is between 60 and 70% more expensive (Buhr, Krahn, & Westdal, 2000; Prentice & Russel, 2009). Air transport is 625% more expensive than shipping by winter road (Buhr, Krahn, & Westdal, 2000). Although it is evident that shippers in the ESLW actively seek the lowest cost mode of transportation possible, the set of modes available are a high-cost subset of the entire range of modes of freight transport in existence.

The performance of the ESLW's freight transportation system is also impeded by its unreliability, something that is determined by the region's climate. All modes of transportation in the region are sensitive to inclement weather (Buhr, Krahn, & Westdal, 2000). The warming trend observed in the region's climate is seen as a threat to the winter road network in two ways over the long-run (Buhr, Krahn, & Westdal, 2000). First, the most recent data available reveals that the average operating window of the road network has decreased by more than 50% (Kuryk, 2003a). Second, the variability in the winter road network's operating window has increased significantly; the standard deviation of the operating window is 3.8 days over the period 1991 to 1997 and 15.2 days over the period 1991 to 2002. The effects of a warming climate could significantly reduce the capacity of the region's winter road network.

2.5 Community Impacts

The unreliability and high cost of the ESLW freight transportation system has a negative impact on the region's population. One of the immediately evident impacts created by the high cost of transportation is that it raises food prices (Manitoba Aboriginal and Northern Affairs, 2003). Food distribution costs in northern communities without road infrastructure are almost four times greater on average than in northern communities with road infrastructure (Manitoba Aboriginal and Northern Affairs, 2003), and the resulting high price of nutritious foods negatively affects community health (Manitoba Aboriginal and Northern Affairs, 2003). In addition, a recent study found food insecurity in the region to be 800% greater than the national average, something that is directly and indirectly influenced by high transportation costs (Kamal, Thompson, & Wong, 2010).

The high cost of freight transportation also acts as a barrier to economic activity in the region. For example, the majority of fresh fish caught in the region cannot bear the cost of transportation to external markets (Kamal, Thompson, & Wong, 2010). The high cost of transport prevents experimentation with economic development projects like Saskatchewan's wild rice seeding program (Archibold, n.d.). As a result, incomes in the region are significantly below average (Manitoba Bureau of Statistics, 2008). This is simultaneously a symptom of high transportation costs and a reason why the high cost of living in the region impacts so severely upon the population.

The unreliability of the winter road network increases risk for the ESLW population and increases the broader costs of sustaining regional freight transportation operations. The winter road network failures of 1998 (Prentice & Thomson, 2004) and 2010 (CBC, 2010) highlighted the sensitivity of the freight transportation system to climatic conditions. The failure of the winter roads in these instances necessitated costly emergency re-supply by air and search and rescue operations.

2.6 The Challenges of Improved Service – The East Side Road Example

There is a need to improve the performance of the ESLW freight transportation system however the range of alternatives available for achieving both reduced costs and improved reliability is limited. Manheim (1979) describes decision alternatives in transportation systems analysis as options (p. 14-18) and the set of consequences for stakeholders that result from the implementation of an option as impacts (p. 18-19). The objective of the decision-maker is to evaluate and implement options that will result in desirable impacts upon the stakeholders involved (p. 14). Given the present situation, the set of alternatives is limited to those that produce significant reductions in cost and increases in reliability. The set of impacts in this type of situation are fixed given that the set of alternatives available, the characteristics of existing freight transportation technologies, and the characteristics of the region are themselves fixed.

The solution to the ESLW freight transportation problem put forward by the Province of Manitoba is the construction of an all-season road network - the East Side Road (ESR) (Manitoba East Side Road Authority, 2012). The provincial government had deemed increased accessibility to isolated regions a priority in its transportation strategy (Manitoba Transport and Government Services, 2005). The initial feasibility study for the ESR was completed in 2000 (Buhr, Krahn, & Westdal), and construction of a small portion of the system was completed in 2012 (East Side Road Authority, 2012a). The project requires the construction of 872 kilometers of roads in total (SNC Lavalin, 2011) and the estimated time to completion is 30 years (East Side Road Authority, 2012c). The road network would connect to the northern ESLW communities through an east-west connection to provincial roads (PR) 373 and 374, while in the south the ESR connects to PR 304 (East Side Road Authority, 2012b).

The impacts of the ESR are what would typically be associated with any large-scale infrastructure project in a similar scenario. It is projected that freight transportation costs could be halved once the ESR is built (SNC Lavalin, 2011). Furthermore, it is expected that the ESR would generate direct and indirect employment during the construction phase of the ESR and economic development opportunities over the long-term (SNC Lavalin, 2011; Buhr, Krahn, & Westdal, 2000).

The costs associated with the ESR are also those typically associated with large infrastructure projects. The estimated construction costs grew from an initial estimate in the hundreds of millions (Buhr, Krahn, & Westdal, 2000) to the most recent cost estimate of $2.7 billion[3] (SNC Lavalin, 2011). Aside from construction costs, the presence of an all-season road can negatively affect the region's wildlife and may expose the region to disruptive land-use patterns over time (Baggio, 2005). Unlimited accessibility to the communities in the region can also bring about negative social and cultural impacts (Buhr, Krahn, & Westdal, 2000).

2.7 Case Summary and Proposition Formulation

Although caution should be exercised in making generalizations based on a single case, the ESLW region is typical of isolated northern regions and serves as a representative case. The purpose of the following propositions is to develop a theoretical understanding of freight transportation systems in isolated regions.

The ESLW is a sparsely populated region that covers a large land area. It lacks a large and long-lasting natural resource base that has historically driven the construction of roads in northern Manitoba. These characteristics lead to there being little economic interest in the region.

P1*: Isolated regions are large in land area and small in population.*

P2*: Isolated regions lack the type of natural resource base that would promote road construction.*

[3] In 2010 dollars.

Air transport is the only mode of transportation available year-round. Although shippers prefer lower-cost modes of transportation, their modal choices are constrained by the seasonal availability of truck and barge service. The reliability of the system is low because of climatic factors. The cost of freight transportation in the region is much higher than in regions that have road access.

P3*: Isolated regions are heavily reliant on high-cost air transport.*

P4*: Modal choice in isolated regions is constrained by seasonality.*

P5*: Freight transportation systems in isolated regions are high-cost and unreliable.*

High transportation costs along with unreliable service lead to the following community impacts. The high cost of transport raises the cost of living and reduces economic development opportunities. The unreliability of the system increases the risk that communities do not receive freight re-supply. ESLW communities experience high rates of food insecurity and disease related to poor nutrition as a result.

P6*: High transportation costs in isolated regions raise the cost of living in isolated regions and act as a barrier to economic development.*

P7*: Community health in isolated regions is negatively impacted by the low performance of their freight transportation systems.*

The solution advanced by the government is the construction of an 872 kilometer, $2.7 billion all-season gravel road network. Although construction has already begun, it is expected to be a long time before the network is completed. In addition, residents have expressed concern about the potential negative impacts derived from unlimited accessibility to the region.

P8*: Achieving satisfactory freight transportation service levels in isolated regions requires the construction of infrastructure.*

***P9**: Infrastructure construction in isolated regions requires a high level of investment.*

***P10**: A change from limited accessibility to unlimited accessibility in an isolated region can lead to unintended and potentially negative community impacts.*

These theoretical propositions have been formulated based on the general characteristics of the ESLW and its freight transportation system. Other isolated regions may differ in terms of their specific characteristics but it is expected that the same general themes apply. For example, the shippers in the ESLW make use of low-cost modes of transportation when they are available (barges and winter-road trucking). Other isolated regions may have access to maritime transport in the summer. The specific modes differ, but the general theme of seasonality prevails. More research into freight transportation systems in isolated regions is warranted, and these propositions can be translated into testable hypotheses that guide these research efforts.

2.8 Conclusion

The preceding case analysis provides insight into northern freight transportation systems and how they impact the communities they serve. The general theme that emerges is that isolated regions are negatively impacted because of the low service levels provided by their freight transportation systems. Moreover, improving service levels is prohibitively expensive. Replication of this research in other isolated regions is warranted to test the propositions formulated in this chapter. These propositions can be used as testable hypotheses, and both confirmatory and contra-indicating cases would improve the theoretical understanding of northern freight transportation systems.

Research into alternative freight transportation technologies is also warranted. The cost of improving freight transportation service levels in isolated regions is high in part because of the characteristics of existing transportation technologies. As seen in the

ESLW case, any increase in service levels requires a massive per-capita investment in infrastructure. This means building roads in the ESLW or in Nunavut it might mean building seaports. A large gap exists in terms of service levels and systems costs between existing northern freight transportation systems and their infrastructure-intensive alternatives based on existing transportation technologies. A new transportation technology that bridged this gap could facilitate economic development efforts and reduce the negative impacts that existing freight transportation systems create. Research into alternative transportation technologies is therefore warranted.

Chapter 3: The Role of Performance Information in Cargo Airship Development

3.1 Introduction

The previous chapter describes the northern freight transportation problem and highlights the need to investigate new transportation technologies. Cargo airships have been advanced as a solution but none have entered service. Lighter-than-air (LTA) technology has been successfully employed in passenger transport (Prentice & Russell, 2009), sightseeing and tourism (Sträter, 2005), advertising (Bartel, 2002) and in various niche roles but never in a freight transportation role. As described in the introduction to this thesis, this chapter demonstrates the need for information that concretely demonstrates the cargo airship's economic performance. A comprehensive literature review on innovation diffusion, innovation development, and stakeholder management is found in appendix A. This served to provide direction for this investigation into why cargo airships have not been adopted and what role performance information plays in that process. A summary of the case made for the cargo airship by its proponents is presented first.

3.2 The Rationale for the Cargo Airship

Arguments advanced in favour of the cargo airship rest on its theoretical cost advantage over other modes of transport in isolated regions (e.g Prentice, Beilock, & Phillips, 2004; Prentice, Russell, 2009; Prentice & Thomson, 2003; Prentice, & Thomson, 2004). Of all modes, air transport is most suitable for accessing isolated regions where there is no economic justification for building roads or railways (Prentice & Thomson, 2004; Hilling, 1996). The two major shortcomings of conventional aircraft are their high operating costs and their need for runways. Conventional aircraft must produce thrust, and therefore must burn fuel, in order to generate lifting force (National Aeronautics and

Space Administration, n.d). In contrast, the lifting force exerted on the cargo airship is provided by the displacement of the surrounding atmosphere by its lifting gas (Hochstetler, 2010). Cargo airships would also not require a runway.

The cargo-carrying capacity of proposed cargo airship designs is significantly greater than that of the types of aircraft typically serving isolated regions. Aircraft serving the ESLW, for example, can carry between 1.8 and 7 metric tonnes (t) (Perimeter Aviation LP, 2009, Prentice, & Thomson, 2004). In comparison, conceptual designs for cargo airships have been advanced that can carry 20t (Hybrid Air Vehicles, 2010a), 50t (Hybrid Air Vehicles, 2010b), and even up to 200t (Hybrid Air Vehicles, 2010c). In addition, cargo airships can accommodate cargo volumes much greater than large military fixed-wing cargo aircraft (Hybrid Air Vehicles, 2010d). The combination of buoyant lift and high cargo carrying capacity means the cargo airship should theoretically be able to move a unit of cargo over a unit of distance at a lower cost than conventional aircraft.

Cargo airship service would theoretically be available all year, and this would lead to indirect economic benefits. For example, commodities that are today shipped in large quantities during the winter-road season and stockpiled throughout the year could instead be shipped year-round (Prentice and Thomson, 2003). This would allow cost savings because of the elimination of inventory holding costs and because purchases could be timed to when prices are favourable (Prentice and Thomson, 2003).

Airships also require no right-of-way infrastructure (e.g Prentice & Thomson, 2003; Sherwood & Prentice, 2010; Prentice & Thomson, 2004; Prentice & Russel, 2009). Aside from the savings in infrastructure costs, a cargo airship freight transportation system would not impose the various environmental and social costs inherent to building roads. The trade-off in terms of service levels between the cargo airship and an all-season road is that they would not provide the same kind of trip-making flexibility a road would (Hilling, 1996). Conceptually, the cargo airship could be a mid-point transportation solution in comparison with existing freight transportation systems and all-season roads.

Despite the rationale for cargo airships, they have not been deployed (Prentice & Russel, 2009). There is debate about whether cargo airships could operate in the north (Woodgerd, 2002; Danneker, 2002; Luffman, 2007; Taylor, 2002). The availability of modern aircraft routing technology (Hochstetler, 2007) and previous operational experience (Van Treuren, 2002) suggest this is not an impediment. Transportation innovations can take several decades to become widely adopted (Ettlie & Vellenga, 1979) however cargo airships have gone unadopted despite being in development since the 1950's (Aereon, 2004). Authors on the subject suggest there is a lack of business confidence in the technology and the solution is government investment (Prentice & Russel, 2009). The lack of business confidence in cargo airships can be explained by reference to the literature on innovation development and diffusion.

The principles of LTA technology are centuries old (Windischbauer & Richardson, 2005). Its application in a cargo carrying role is a novel approach to solving a particular transportation problem. Everett M. Rogers, the most widely cited author in the field of innovation diffusion research, defines an innovation as essentially anything perceived as new by its potential adopters (2003).

Although LTA technology is centuries old, the cargo airship is nevertheless an innovation because it is a combination of technologies that have so far not been integrated for use in a particular role. Figure 3 illustrates LTA as the core technology that is supplemented by component technologies such as lightweight materials, flight control systems, and buoyancy control systems. The core technology of lighter-than-air aviation is not an innovation *per se* but the combination of the core and component technologies and their application to carrying cargo is an innovation. Treating the cargo airship as an innovation provides a path for investigation into why there is a lack of business confidence in the technology.

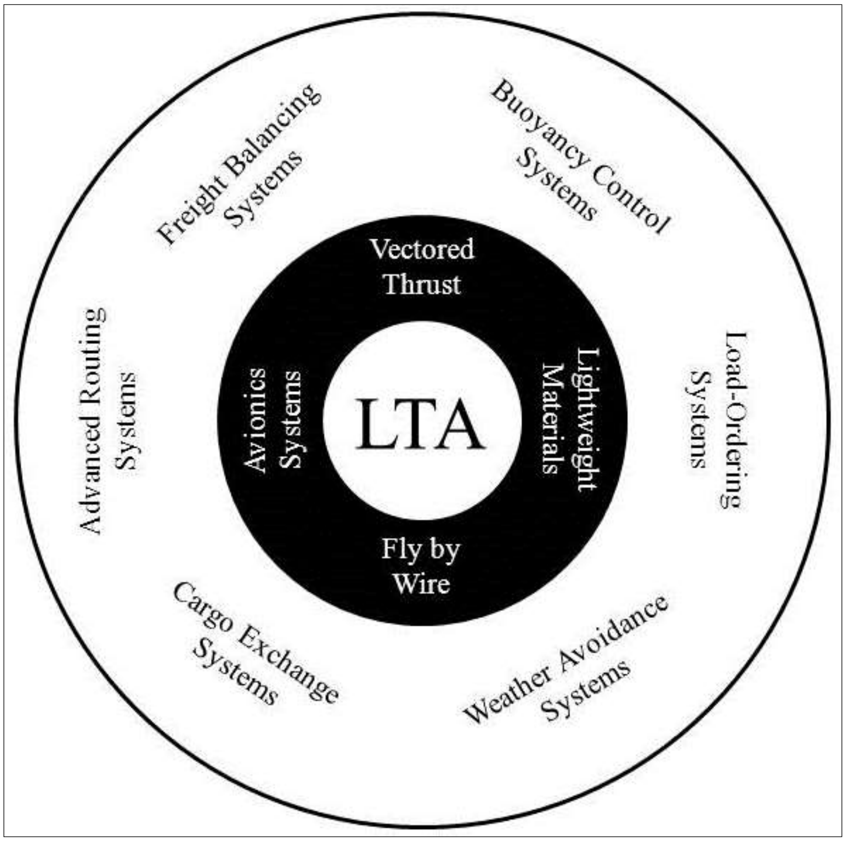

Figure 3 – An illustration of the layers of technology in the cargo airship.

A common bias in innovation research is a tendency towards blaming individuals for failing to adopt an innovation when the problem might be related to the innovation itself or the actions of its developer (Rogers, 2003). The following literature review illustrates that innovation adoption decisions involve a process of uncertainty reduction on the part of the potential adopter. Individuals require information about the innovation that addresses the specific uncertainties they experience, and the innovation will not be adopted if this information is unavailable.

3.3 Innovation Diffusion

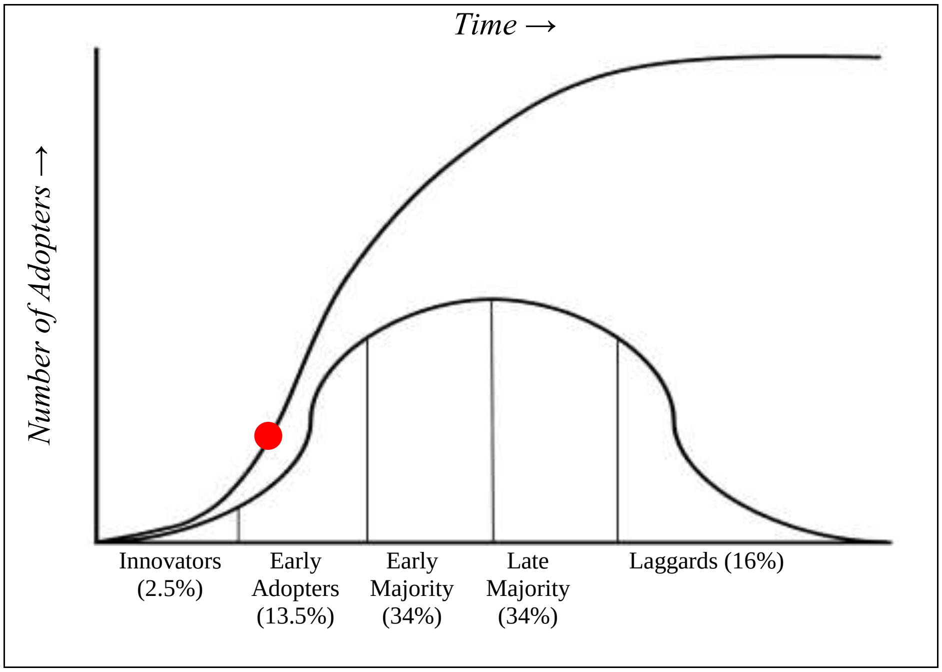

Figure 4 - The distribution of innovation adopters and the cumulative adoption S-curve. Adapted from Rogers (2003, p. 273; p. 281).

Prentice and Russell (2009) argue that airships have not reached their tipping point. Figure 4 illustrates the typical pattern of adoptions over time. The tipping point is marked by a dot on the adoption curve in figure 4. It is the point in an innovation's diffusion process when the rate of adoption increases dramatically once uptake of the innovation reaches between 10% and 20% of the target population (Rogers, 2003).

Innovation diffusion theory and related literature provide a path for investigating the causes behind the cargo airship's lack of commercial success. It has been applied to study a variety of technologies and practices including radio frequency identification systems (Wang et al, 2011; Thiesse et al, 2011), information systems (Agarwal & Prasad, 1997; Russell & Hoag, 2004), and bus ridership (Schwartz, 1980). The following sections provide a concise application of this theory to the context of the cargo airship to understand why this technology has not diffused.

3.4 The Cargo Airship's Characteristics as an Innovation

As stated earlier, the purpose of this chapter is to investigate the impediments to the cargo airship's diffusion. An innovation's rate of diffusion, and indeed whether or not it is adopted at all, has been shown to be moderated by at least five innovation characteristics. These include the innovation's relative advantage, compatibility, complexity, trialability, and observability as perceived by the potential adopter (Rogers, 2003). Cargo airships are unlikely to be incompatible with end-user needs or too complex to operate in comparison with conventional aircraft. This section therefore focuses on the cargo airship's relative advantage, trialability, and observability.

The case for the cargo airship outlined at the beginning of this chapter mainly rests on its economic relative advantage. Its primary appeal is that it would provide low cost heavy lift air transport. Quantitative evidence of the cargo airship's economic advantage, however, is only available in one research paper (Prentice & Thomson, 2004). The information that is widely available about cargo airships discusses the abstract principles behind why this technology might provide an economic advantage. This type of information is effective for educating adopters on why an innovation might work (Rogers, 2003) but is not persuasive in adoption decision-making. An individual is more likely to adopt an innovation if information is available that concisely and concretely describes the consequences of adoption (Myers, 1977; Harborne, Hendry, & Brown, 2007). Thus there is a gap in the quality of information about the cargo airship's economic relative advantage.

On the other hand, there is ample concrete evidence available of the financial cost and risk of cargo airship development. Potential investors can readily find out that hundreds of millions of dollars have been spent on cargo airship development over the last two decades (Government Accountability Office, 2012; Pohlmann, 2009), and that developing a prototype of a cargo airship might cost approximately $80 million (Standing Committee on Transport, Infrastructure and Communities, 2013). The information available about cargo airship development outcomes superficially shows that these are high risk endeavours. For example, investors in CargoLifter lost hundreds of millions of dollars when the company declared bankruptcy, and the program did not result in the construction of a heavy-lift cargo airship (Pohlmann, 2009). The balance of information available between the cargo airship's economic advantages and disadvantages is heavily weighted towards the latter.

An innovation's trialability refers to the degree to which a potential adopter can gain first-hand experience with the innovation at low risk and cost (Rogers, 2003). As mentioned above, the cost to build the first cargo airship or a prototype is very high. It is impossible for potential cargo airship adopters to experience the potential benefits of the technology without a very large, and potentially risky, investment.

Lastly, the cargo airship is more likely to be adopted if the potential adopters can readily observe the consequences of adoption (Rogers, 2003): Observation of adoption consequences can come from first-hand experience with an innovation or by observing the consequences others have experienced. It is impossible for potential adopters to observe the potential cost savings cargo airships could provide because none exist, and a large investment is required to build the first cargo airship to demonstrate its performance. Conversely, the negative outcomes from investment in cargo airship programs are readily observable.

The principles behind the cargo airship's functioning are described in great detail in the arguments made in favour of the technology however information that concretely specifies the economic advantage of the cargo airship is unavailable. Information about the potential negative consequences of investment in cargo airships is readily available. Thus a bias against the adoption of the technology exists.

3.5 Cargo Airship Development Efforts

Two cargo airship prototypes have flown within the last decade however there are many that exist as concepts. Thus the technology is still in its nascent stages of development. This section investigates the impediments to cargo airship diffusion that relate to the management of the technology's development.

As mentioned earlier, private investment in cargo airship development is scarce because of a lack of business confidence in the technology (Prentice & Russel, 2009). One reason for this lack of business confidence is that the readily available information available about failed development efforts to potential cargo airship adopters might be interpreted as a flaw in the technology. Further inquiry reveals evidence that these development programs failed because of flaws in how the programs were managed rather than insurmountable technical problems.

As an illustrative example, the Long Endurance Multi-mission Vehicle (LEMV), a proposed hybrid-type surveillance airship, was originally put on an 18 month development schedule (Warwick, 2013). Whether or not this was an adequate amount of time to develop a new transportation technology is unclear. However, development programs that are rushed are much more likely to result in failure and re-work (Cooper, 1990). Reports from the LEMV's development show that this is indeed what the program experienced; the program experienced several delays because of technical problems and the prototype that was delivered failed to meet its performance specifications (Inside

Defense, 2013). Thus in this case, the problem was most likely not with cargo airship technology but rather in how the development program was managed.

Cargo airship developers may be creating greater uncertainty for investors by asking for large sums of money to build a prototype or to enter into production when their design exists in conceptual form only. Investors need increasingly concrete and higher quality information about an innovation's financial and technical performance before they will invest (Byrne & Polonsky, 2001; Cooper, 1990). Cargo airship developers create greater uncertainty, and consequently greater resistance, for investors when they ask for large-scale investment when information about the potential payoff is lacking. Developers can minimize investor uncertainty by instead asking for smaller investments to develop concrete information about the cargo airship's financial and technical performance (Tzokas, Hultink, & Hart, 2003).

3.6 Cargo Airship Adoption Decision Context

The cargo airship's diffusion exists in a multi-stakeholder environment. Greater stakeholder involvement in diffusion situations creates greater complexity (Hall & Martin, 2005). These are much more complex diffusion environments because adoption decisions are interdependent. One stakeholder group might only be able to adopt an innovation if another stakeholder group has adopted first. In the case of the cargo airship, regulators and investors, whether government or private, play a role in taking that first step by adopting the technology, yet they have so far been unwilling to do so (Prentice & Thomson, 2003). Thus carriers, shippers, suppliers, and others who might benefit from adopting cargo airship technology are unable to do so.

Overcoming this lack of stakeholder action again requires the provision of concrete information about the cargo airship's benefits. Adopters and stakeholder groups vary from one another. They each have different needs and different perceptual filters (Rogers, 2003; Franke & Krems, 2013; Cantor, Corsi, & Grimm, 2008) that lead to each having a unique set of uncertainties about an innovation. As a consequence, information about the cargo airship's financial and technical performance should be specific to the needs of each stakeholder group. For example, government stakeholders need information that describes the social consequences of cargo airship adoption, while investors, carriers, and shippers require information that focuses mainly on economic opportunity. Ultimately, however, all stakeholder groups need information that is based on whether or not cargo airships will provide transportation cost savings, and if so to what degree.

3.7 Conclusion

This chapter illustrates the gap in the quantity and quality of cargo airship performance information between what stakeholders require and what is available to them. Rogers (2003) describes the innovation adoption-decision process as one of uncertainty reduction. An innovation is not adopted if potential adopters perceive uncertainty about the consequences of adoption. The role of information in the diffusion process is to reduce uncertainty to a point where the decision-maker feels confident in adopting the innovation. The central theme from the review of the cargo airship case is that information about the cargo airship's economic performance is lacking. This is a critical shortcoming because all stakeholders involve have informational needs that are based on the potential transportation cost savings afforded by cargo airship technology. The lack of business confidence in this technology and stakeholder action that causes the cargo airship to remain un-adopted can be attributed to this lack of performance information.

A counter-example to the cargo airship is the case of the self-driving car. Like the cargo airship, development of this technology has been ongoing for several decades (Schmidhuber, n.d). Cargo airships have attracted hundreds of millions of dollars in investment over the last decade or so from the United States government and private shareholders in Europe (Government Accountability Office, 2012; Pohlmann, 2009). The self-driving car has attracted a similar level of investment from European governments (Eureka Secretariat, 2010), automobile companies (Woollaston, 2013; Piejko, 2011; Hanlon, 2007), and most interestingly from Google (Google, 2010). Unlike the cargo airship, however, regulators are acting in support of driverless car technology, at least in the United States where development is taking place. The National Highway Traffic Safety Administration (2013) recently published a policy position on driverless cars that encourages a cautious yet permissive approach to deploying the technology on public roads for further testing.

There is a striking contrast between the information available about the two technologies. The arguments made in favour of the cargo airship discussed at the beginning of this chapter are abstract. Although they may be compelling to some, their lack of specificity limits their appeal. In contrast, developers of driverless cars have been able to communicate concrete performance and consequences information to stakeholders. For example, Google has stated they expect the diffusion of driverless cars to reduce road accidents and congestion by 90% (Mui, 2013). Google reported that its driverless cars had completed 300,000 accident-free miles while the car was driving under its own control (Lardinois, 2012). This concrete information provides the motivation for stakeholders to support the technology. Conversely, this type of information is unavailable for cargo airships. Without this information, motivation for stakeholders to invest in developing cargo airship technology or to create a permissive regulatory environment is lacking.

The need for improved transportation service in isolated regions in northern Canada is well established. Cargo airships have been advanced as a solution to this transportation problem however stakeholders in Canada have so far not taken sufficient action to develop the technology. This chapter highlights the need for concrete information that describes the economic consequences of cargo airship adoption. Arguments made in favour of cargo airships so far are too abstract to compel stakeholders to take action. Thus there is a need for information that clearly demonstrates whether or not cargo airships can provide low-cost transportation service in isolated northern Canadian regions.

Chapter 4: North West Company Background and Cargo Airship Cost Models

4.1 Introduction

This chapter provides an overview of the two sources of data used for the cargo airship's economic performance analysis. Background information on the North West Company (NWC) and the selection of case regions is presented first. The balance of this chapter is devoted to a description of the cargo airship operating cost model and the methodology for assigning cargo airship operating costs to NWC freight transportation trips.

4.2 The North West Company – Background

The NWC was founded in the 17th century (The North West Company(a), n.d) to compete with the Hudson's Bay Company in the Canadian fur trade (Keith, 2001). The NWC has evolved into an international retailer dealing with groceries and general merchandise that specializes in serving remote communities in northern Canada, Alaska, and island communities in the Caribbean and Guam (The North West Company, 2013).

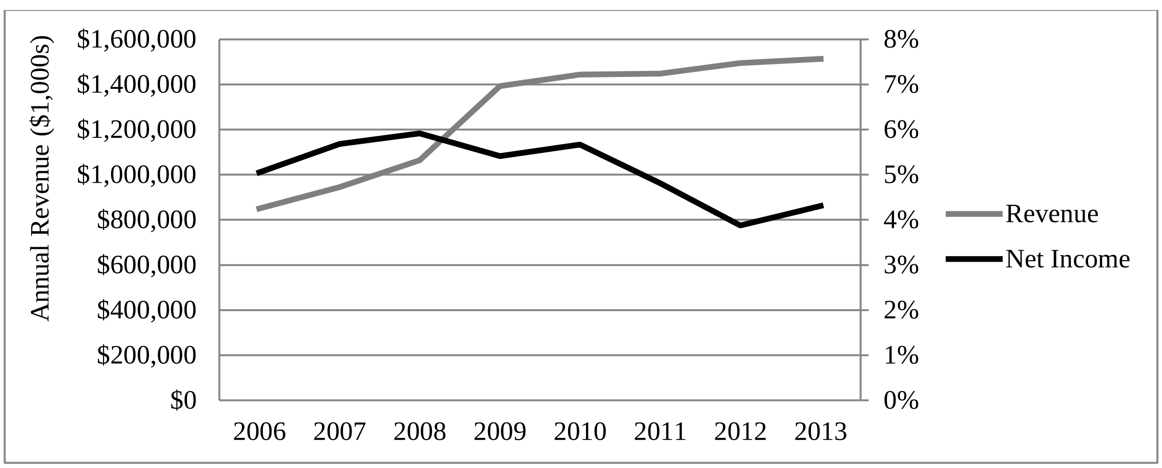

Figure 5 – NWC's revenue ($1,000's) and net income (%), 2006 - 2013. Source: The North West Company (2012; 2010).

Revenue in millions of dollars and net income as a percentage of revenue for the eight most recent years are presented in figure 5 (The North West Company, 2013; The

North West Company, 2011). The comparison between revenue and net income illustrates the thin margins present in the food retail business. The company has achieved average annual revenues of $1.2 billion Canadian Dollars (CAD) over the eight year period. Net income as a percentage of revenue averaged 5.1% over that time.

The NWC achieved revenues of $1.5 billion CAD in 2011. Approximately 69% of that was earned through the company's Canadian operations. Within Canada, the NWC operates six branded retail chains and a wide range of wholesale companies that trade in food products, financial and medical services, and fur and Inuit art (The Northwest Company(b), n.d). Among the retail store brands operated by the NWC, the most extensive is their Northern Store chain. The NWC operates 123 Northern Store outlets in seven provinces and three territories across Canada. The dataset provided by the NWC (Shipper 1, 2013) shows that the company shipped 45,511.4t of freight to stores in its network. These stores are mainly located in small, remote northern communities, and as a consequence the NWC has a complex and unique logistics network in comparison with retail chains operating in major urban centres across southern Canada.

4.3 The Dataset

The NWC provided freight transportation data for their entire network of stores across Canada. The dataset originally provided by the company describes freight origins, destinations, quantities, modes, freight types (food or general merchandise (GM)), and costs for air and truck transport. The objects in the dataset are carrier invoices that have been transcribed into a spreadsheet. The NWC also provided maritime freight transportation data for one of the case regions. This dataset is of extreme value because no comprehensive dataset that describes freight movements in northern Canada is publically available.

Although this dataset is invaluable, its limitations should be noted. One potential limitation of this dataset is that it may not describe all of the NWC's freight movements. This could be due simply to transcription errors. Secondly, dimensional data are not described in the dataset therefore it is only possible to discuss freight tonnage and not volume. Third, indirect logistics costs, such as inventory holding costs, are not described in the dataset. Finally, descriptions of subsidized freight flows are incomplete and therefore excluded in this analysis[4]. This dataset does, however, describe actual freight flows and actual transportation costs in regions that have received very little research attention previously. This research project would not have been possible without the data provided by the NWC.

With these potential limitations in mind, the cost comparison analysis is limited to determining whether cargo airships can compete on direct transportation costs. The dataset allows for an assessment of whether or not the cargo airship can compete in the current northern freight transportation market given an assumed level of cargo airship utilization. This analysis assumes there is sufficient freight transportation demand in northern Canada for at least one cargo airship to achieve full utilization and the NWC can purchase capacity aboard the airship as needed.

4.4 Selection of Cases

The NWC provided air and truck freight transportation data for their entire retail store network and maritime data for the Kivalliq region in Nunavut. The formulation of case regions is based on a set of selection criteria meant to ensure cross-case comparison.

[4] This refers to Nutrition North (Nutrition North Canada, 2012) or Food Mail (Aboriginal Affairs and Northern Development Canada, 2010) freight flows. In addition to these flows not wholly being described in the dataset, the issue of subsidized freight rates is unique. Cargo airship freight rates would likely be subsidized to the same degree as existing modes of transport making comparison unneccessary.

Cross-case comparison provides the opportunity for generalizing the findings from the cost comparison analyses. Examination of the NWC's freight re-supply network showed certain regions of greater interest for this research than others. Given this finding, the selection criteria are as follows:

1. The regions must possess a relatively large number of communities and a relatively large population.
2. The regions must have no all-season roads or other surface infrastructure.
3. The regions must be relatively different from one another in terms of average distances, modal availability and split, and quantities of freight.

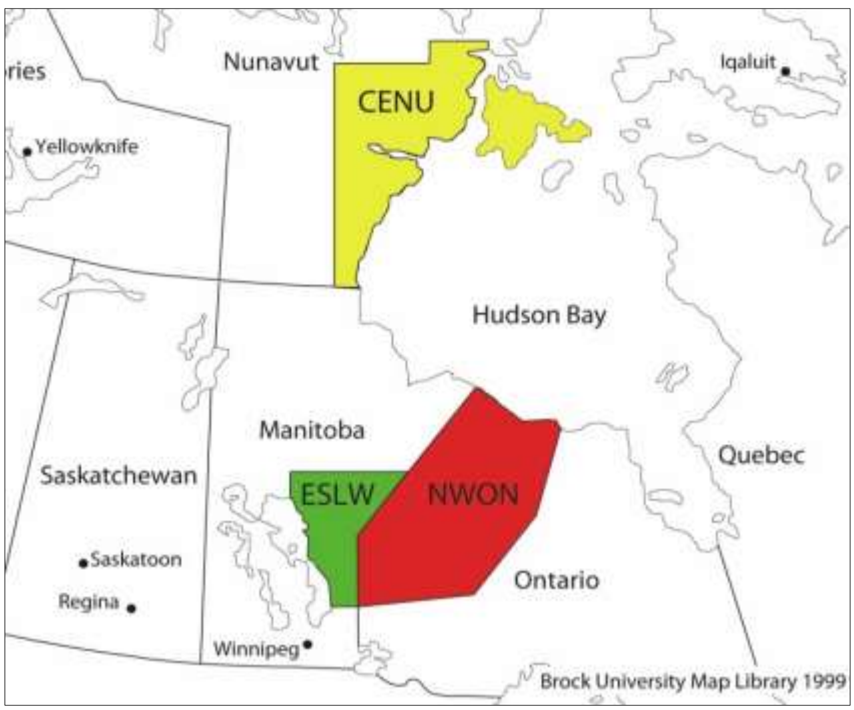

Figure 6 - Map of three case regions in Canada. *Modified from*: Canada [computer file]. (no date). St. Catherines, Ontario: Brock University Map Library. Available: Brock University Library Controlled Access http://www.brocku.ca/maplibrary/maps/outline/North_America/canada.pdf. Brock University provides this and other maps for free use by the public.

The first two criteria ensure a sufficient amount of transportation activity in each region while the last criterion is included in order to enhance the generalizability of the findings from these analyses. Three of the regions meet these criteria: The east-side of Lake Winnipeg (ESLW) in Manitoba, north-west Ontario (NWON), and the Kivilliq region in central Nunavut (CENU). A map of the three regions is illustrated in figure 6. Summary statistics shown in table 2 describe how each region differs in terms of geographic size, the number of communities and population, average air and winter road transport distances, and freight quantities.

Table 2 - Summary statistics for the three case regions.

Region	km^2	Comm.	Pop.	WR	Air	Air/ST	t	T/C
ESLW	38,146	11	12,673	607	258	68/32	6,173.6	0.49
NWON	117,537	11	8,221	958	482	87/13	4,510.0	0.55
CENU	147,553	6	7,995	NA	1,041	66/34	3,303.0	0.41

km^2: Land area of region in square kilometers.
Comm.: Number of communities in each region.
Pop.: Population of each region.
WR: Average winter road distance in kilometers, weighted by total winter road trucking MTK in each region.
Air: Average air distance in kilometers, weighted by total air transport MTK in each region.
Air/ST: Modal split between air and surface transport in percentage (Winter roads in the ESLW and NWON regions and maritime in the CENU region).
t: Total quantity of freight shipped to the region's stores in metric tonnes.
T/C: Total freight quantity per capita.

These isolated regions are the largest and most populated in which the NWC operates. All three regions vary significantly in terms of land area. Population density for the ESLW, NWON, and CENU are 0.33, 0.07, and 0.05 persons per square-kilometer respectively. Lower population densities suggest greater distances must be overcome for freight re-supply. This is in part reflected in the increasing average winter road distances in the NWON in comparison with the ESLW and in the increasing average air trip distances across all three regions.

Figure 7 summarizes the freight quantity demand and model and freight type splits for each region. Modal split proportions and availability vary across the three regions. The split between air and trucking in the ESLW is relatively balanced in comparison to the NWON, while no trucking is used in the CENU region. The latter region does, however, receive freight by maritime transport. This is the only region of the three that receives freight by this mode, making the comparison with the airship more illuminating.

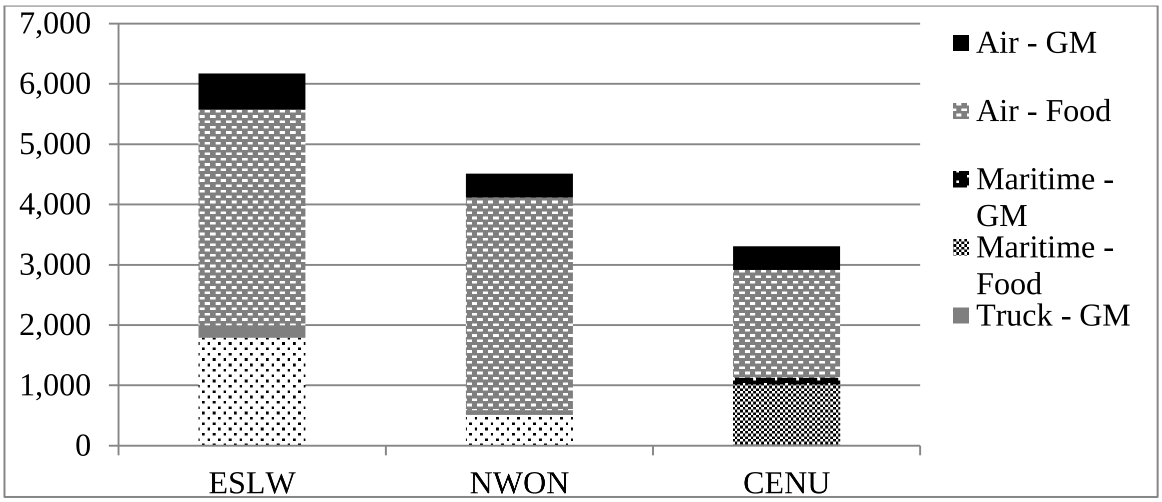

Figure 7 - Summary of freight quantity in metric tonnes by mode and type for each case region.

Total freight quantities shipped by air and truck into the three regions also vary between the three regions. On a per capita basis, the ESLW, NWON, and CENU regions each received 0.49t, 0.55t, and 0.41t of freight.

4.5 Cargo Airship Operating Cost Model

Several cargo airship developers were contacted to provide operating cost data. The following are descriptions of the companies that were contacted the cargo airship development programs they are undertaking.

1. **Hybrid Air Vehicles (HAV)**: HAV was awarded a contract to design and build a non-rigid hybrid[5] airship for the United States military in 2010 (Government Accountability Office, 2012). As a result of this development project, HAV joined the ranks of a handful of cargo airship developers to have successfully flown a modern cargo airship prototype. Although the United States military cancelled this program, HAV is continuing development of larger versions of the prototype they flew. Dubbed the AIRLANDER, HAV envisions variants capable of carrying 20T, 50T, and 200T of cargo (Hybrid Air Vehicles, 2010e).
2. **Lockheed Martin (LM)**: LM's cargo airship is also a non-rigid hybrid design called the SkyTug. LM first successfully flew a scaled prototype of the SkyTug in 2006 (Mick, 2009). LM is the largest and most well-resourced company developing cargo airship technology.
3. **Aeros**: Aeros is developing the Aeroscraft, a rigid-type cargo airship deigned to carry 66 tons of cargo or more (Aeros, 2012). Aeros has secured development funding from various U.S government agencies, and has built a scaled prototype of their airship. The company expects to start flight tests in the near future. This cargo airship design features a helium compression system to control aerostatic lift.
4. **Varialift**: Varialift is developing a range of rigid-type cargo airships that feature a monocoque aluminum structure and a helium compression system to control aerostatic lift (Varialift, 2013). The company has so far successfully demonstrated and patented their buoyancy control system. They are pursuing

[5] The characteristics of various cargo airship designs have been discussed at length in previous research. Interested readers can consult Liao & Pasternak (2009) for a comprehensive review of this topic.

development of a 50T capacity cargo airship, and envision a range of airships with capacities far in excess of this.

One cargo airship developer provided operating cost data that could be used for calculating cargo airship trip costs. The operating cost items included in this model are as comprehensive as the models used in previous aircraft operating cost research (Swan & Adler, 2006). It should be noted, however, that the cargo airship described by this operating cost model is in its early stages of development. Because of this, the operating cost model should be viewed as a best available estimate rather than actual cargo airship operating costs. Further development and prototype testing will reveal the accuracy of these estimates.

The operating cost data have been modified for this research to provide a more conservative estimate of the cargo airship's performance. First, the cruising speed was reduced to approximate the speeds achieved by large rigid airships of the Zeppelin era (Liao & Pasternak, 2009). The helium leakage rate was increased to 5% per year. Although this is a more conservative figure, it is still half the leakage rate of modern non-rigid airships (Prentice & Russell, 2009). Non-rigid airships maintain their shape by pressurizing the lifting gas whereas the structure of a rigid airship is provided by its internal frame. The leakage rates of the former are higher than the leakage rates of the latter. The length of the lease term for the cargo airship and its hangar were decreased to 12 years and 25 years respectively. A 12 year lease term is the maximum offered by aircraft financing companies (General Electric Aviation Capital Services, 2011). Some of the staffing requirements have been adjusted according to assumptions that are outlined subsequently. Finally, a profit margin based on cost-plus pricing is added to reflect the compensation that a cargo airship used in a for-profit enterprise would require.

Table 3 - The cargo airship's general operating characteristics and finance terms.

Cruising Speed	125 km/h
Maximum Payload	50t
Operating Hours per Year	7,200 Hours
Envelope Volume	Approx. 275,000 M^3
On-board Crew Requirements (Minimum)	1 Pilot, 1 Loadmaster

Because the shipper requested all dollar amounts remain confidential, the operating costs of the cargo airship in dollar amounts must also remain confidential. Table 3 describes the general operating characteristics of the cargo airship. As stated earlier, the cruising speed of the cargo airship is 125 km/h and it has a useful payload capacity of 50 metric tonnes (t). The operating cost data specifies it is capable of operating 24 hours per day over 300 days per year for a total of 7,200 operating hours[6]. The remaining 65 days are assumed lost to scheduled and unscheduled maintenance, as well as to service disruptions due to inclement weather or other unforeseen circumstances.

The cargo airship's operating costs are outlined in table 4. Total operating costs are composed of variable costs and fixed costs. Fuel consumption and maintenance requirements are variable cost drivers that accrue with each block hour[7]. Fixed costs include the cost of owning the airship and its hangar, insurance, helium leakage and loss, and staffing. Current regulations in Canada set a limit of 1,200 flying hours per year per commercial pilot (Transport Canada, 2013). Assuming the same regulations apply to cargo airship pilots, a minimum of six pilots are needed to operate the airship year-round. The number of loadmasters required is set to match the number of pilots needed so that

[6] See appendix B for a preliminary assessment of demand potential for cargo airship combination passenger and cargo transport service. Assuming 7,200 hours of utilization from a market perspective appears reasonable based on this analysis.

[7] Block hours include the time between when an aircraft sets into motion until when it comes to rest at the end of a trip (International Civil Aviation Organization, 2013). This includes time spent on taxiing, take-off, approach, landing, and in-flight time.

they form a unitized flight crew. Ground crew staffing requirements are based on the assumptions that four ground crew working hours are required for every one hour of cargo airship operating time and that each ground crew member can work 2,000 hours per year.

Table 4 - Cargo airship operating cost drivers.

Variable Operating Costs	
Fuel Consumption Rate (Per Hour)	900 Liters
Maintenance Costs Rate	Per Block Hour
Fixed Operating Costs	
Cargo Airship Lease Terms	
Lease Period	12 Years
Residual Value	30%
Effective Monthly Compound Interest Rate	0.7974%
Hangar Mortgage Terms and Depreciation	
Amortization Period	25 Years
Effective Monthly Compound Interest Rate	0.4074%
Depreciation Schedule	Straight-line, 20 years, no residual value
Insurance	
Annual Hull Insurance Cost	10% of cargo airship purchase price
Annual Property and Liability Insurance Cost	5% of cargo airship purchase price
Helium Leakage/Loss	
Annual Helium Leakage/Loss Rate	5% of envelope volume
Annual Staffing Requirements	
Pilots	6
Loadmasters	6
Ground Crew	15
Load Planner/Dispatcher	1
Profit Margin	
Margin Type	Cost-Plus
Profit Mark-up	35%

Finally, a profit margin is added to account for enterprise operating costs and a return on investment that a cargo airship operator would seek. Freight rates are set in the operating cost model using cost plus pricing. Previous research has shown it is a common approach for setting prices (Guilding, Drury, & Tayles, 2005). Carriers that operate in the north do not publish financial statements therefore an arbitrary margin of 35% is used because information about industry-standard profit margins is unavailable.

4.6 Transportation System Modelling

Cargo airship trips can be modeled in two ways. The simplest from an analytical perspective is point-to-point whereby the cargo airship departs from an origin carrying a full load, flies directly to a store destination, and returns to the origin empty. The alternative is to model chained trips. In this case, the cargo airship departs from an origin carrying a full load and delivers less-than-full loads to multiple origins. The cargo airship flies a circuit within each region and eventually returns to the origin empty. These alternatives are illustrated in figure 8 below.

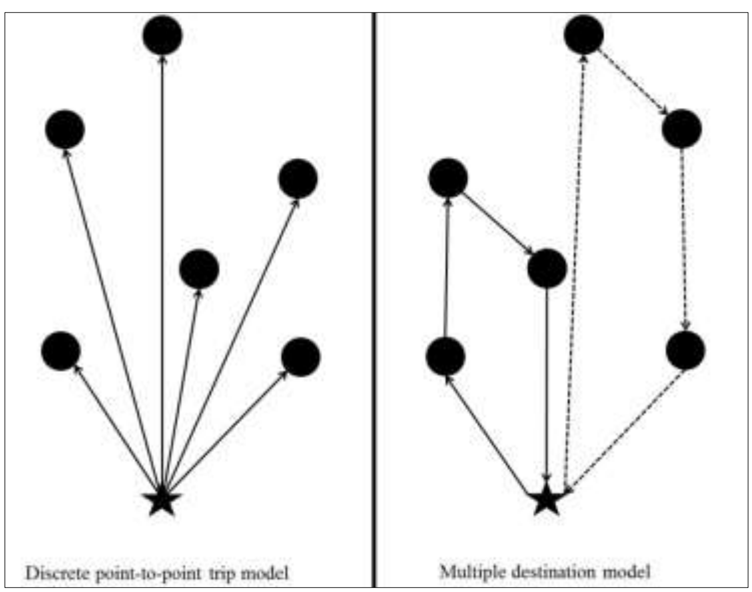

Figure 8 – Illustration of trip modelling alternatives.

Modelling the cargo airship's cost performance assuming point-to-point service with full front-hauls and empty back-hauls inevitably results in the highest cost alternative out of all possible routing options. This scheme does not make a routing choice based on cost, travel time, or trip frequency optimization. The alternative is to formulate a sophisticated mathematical model to achieve certain objectives related to service level objectives (García et al., 2013; Bonomo et al., 2012; Federgruen & van Ryzin, 1997). The weakness of this alternative approach is the level of complexity involved in developing the mathematical models that represent the underlying transportation system. Indeed, the amount of computational work required to solve increasingly complex routing problems grows exponentially (Laporte, 2010). Chained trips could be modelled by arbitrarily clustering communities together based on geographic proximity. This may provide a routing solution that is lower-cost than point-to-point service but could also produce a solution that is higher-cost than a routing option based on optimization schemes because other factors, such as levels of demand in each community, may influence routing more than geographic proximity.

The point-to-point modelling approach provides a conservative estimate of the cargo airship's relative cost performance. This is appropriate given the stage of development of the cargo airship under analysis. Selecting this routing option provides insight into whether the cargo airship can provide lower cost freight transport in a worst case scenario. In addition, the development of a complex routing model constitutes a major research endeavour unto. This would be appropriate for future research to determine if further cost savings could be achieved in the cargo airship's best-case scenario. Research attention in this thesis is devoted instead to building a foundation upon which future research can be built.

The approach used in subsequent cost comparison analyses is the assumption of point-to-point trips between O-D pairs with empty backhauls. Trip costs are assigned to the NWC based on the full return trip cost for full loads. Trip costs for partial loads are assigned to the NWC based on the proportion of the cargo airship's total capacity consumed by the NWC for that particular trip. For example, if the total freight demand in one community is 75t, then the cost assigned to the NWC for using a cargo airship with a payload capacity of 50t would be the cost of 1.5 trips to that community. The assignment of partial trip costs in proportion to capacity consumed reflects the assumption that the price-elasticity of demand for freight transportation service for all shippers in the case study regions are equal and that the total freight transportation flows into any of the three regions are greater than the flows from the NWC's operations. This assumption is made because data are unavailable to establish price elasticity of demand between shippers. Further research into freight transportation flows in northern Canada could provide this insight.

4.7 Cargo Airship Costing

The proceeding analyses use actual freight rates as a baseline for comparison. These freight rates reflect what freight transportation companies charge to shippers to ensure profitability. Cargo airship costs are therefore calculated to simulate what a carrier operating a cargo airship would charge the NWC for its services. The operating cost drivers specified in the model are operationalized into costs that accrue per occupied hour and per block hour. Occupied hour and block hour costs are then used to compute variable and fixed trip costs that are assigned to the NWC based on their requirements[8].

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[8] An example for calculating and comparing transportation costs is found in appendix C. This example is based on hypothetical transportation costs to illustrate the mechanics of the cost comparison analyses.

Block hours are calculated as the amount of time that elapses between the cargo airship taxiing for take-off to when it comes to a rest after completing the return leg of its journey. Total block hour requirements depend on trip length, the cargo airship's cruising speed, and the amount of time it takes for take-off and landing. The cost model specifies 20 minutes each for take-off and landing and a cruising speed of 125km/h. Net in-flight hours are calculated by subtracting 41.7km from the trip distance to account for the distance covered during the cargo airship's take-off and landing phases. Two-thirds of a block hour is added to account for these portions of the trip. Block hours are then doubled to account for the return trip. The equation for calculating the number of block hours required to complete a trip is given in equation 1.

Block hours required for one round-trip (*B*):

$$B = 2\left[\left(\frac{(\text{Trip Distance - 41.7})}{125}\right) + \left(\frac{2}{3}\right)\right]$$

Equation 1 - Equation for block hour requirements.

Block hour costs are the sum of the direct hourly cost items multiplied by the number of block hours consumed in a given trip. The two direct variable cost items specified in the operating cost model are fuel consumption and maintenance costs. Maintenance costs are pre-defined in the model as a cost per block hour. Fuel costs must be derived from the fuel consumption rate and fuel costs per liter. The equations for fuel costs per block hour and total variable costs per block hour are expressed in equations 2 and 3 respectively.

Fuel cost per block hour (*F*):

$$F = (\text{Fuel Cost/Liter} \times \text{Fuel Consumption/Block Hour})$$

Equation 2 - Fuel cost per block hour equation.

Total cost per block hour (*BHC*):

$$BHC = B(F + M)$$

BHC : Cost per block hour
B : Number of block hours
F : Fuel cost per block hour
M : Maintenance cost per block hour

Equation 3 - In-flight hourly costs.

Fixed cargo airship operating costs are assigned to occupied hours. Occupied hours include the time between when the cargo airship begins to be loaded before making a trip to when it returns to its point of origin and begins to be loaded again. Occupied hours are charged at a rate that pays for all fixed operating costs. Total occupied hours required for a given trip include the number of block hours plus the time it takes to load and unload the cargo airship. Loading or unloading the airship is specified in the operating cost model as taking 40 minutes each, or 80 minutes total in combination. This is expressed in equation 4.

Occupied hours required for one round-trip (*O*):

$$O = B + \left(\frac{8}{6}\right)$$

Equation 4 - Occupied hours per trip.

Although the number of occupied hours includes the number of block hours required by a trip, the cost per occupied hour differs from the cost of one block hour. The occupied hour costs are a function of the fixed costs that accrue from owning the cargo airship, the hangar, insurance, helium leakage and loss, and staffing. The equations for calculating annual fixed costs and the cost per occupied hour are given on the following page.

Annual insurance costs (*I*):

$$I = \text{Cargo Airship Purchase Price} \times (\text{Annual Hull Insurance Rate + Annual Liability Insurance Rate})$$

Equation 5 - Annual insurance cost equation.

Annual helium leakage and loss costs (*H*):

$$H = (\text{Annual Helium Leakage and Loss Rate} \times \text{Envelope Volume})$$

Equation 6 - Annual helium cost equation.

Annual staffing costs (*S*):

$$S = \begin{bmatrix} (\text{Annual Pilot Salary} \times \text{Number of Pilots}) \\ +(\text{Annual Ground Crew Salary} \times \text{Number of Ground Crew}) \\ +(\text{Annual Planner/Dispatcher Salary} \times \text{Number of Planner/Dispatchers}) \end{bmatrix}$$

Equation 7 - Annual staffing cost equation.

*NB: For trips that require greater than 8 occupied hours, the cost of a second pilot is added at an hourly rate. This assumes that additional pilot hours can be purchased in direct proportion to demand. A pilot can work 1,200 hours per year, therefore the hourly charge for the second pilot is simply $P = \frac{\text{Annual Pilot Salary Cost}}{1{,}200}$.

Cost per occupied hour (*OHC*):

$$OHC = \frac{(L + G + I + H + S)}{AOH}$$

OHC : Occupied hour cost

L : Annual cargo airship lease cost

G : Annual hangar mortgage cost

I : Annual insurance cost

H : Annual helium cost

S : Annual staffing costs

AOH :Annual operating hours

Equation 8 - Occupied hour cost calculation.

The cost for one trip is calculated as the sum of total block hour and occupied hour costs. Shippers are charged based on the proportion of the cargo airship's payload capacity they use given the assumptions of 100% cargo airship utilization and equal price elasticity of demand for freight transportation service between shippers. Partial trips are rounded up to the nearest tenth of a trip. Total trip costs are then marked-up by 35% to generate a freight transportation price charged to the shipper. This is expressed in equation 9.

Price charged to shipper (*P*):

$$P = 1.35\left[\left(\frac{\text{Shipment Weight (MT)}}{50}\right)\times\left(\left(B\times BHC\right)+\left(O\times OHC\right)\right)\right]$$

Equation 9 - Equation for calculating transportation price charged to shipper.

The freight transportation prices charged by carriers are a cost of business to the NWC. The cargo airship would be a part of a multi-modal system the NWC uses to deliver freight to the isolated regions it serves. Total annual freight transportation costs to the NWC are the sum of all freight movements by all modes to all communities in all regions. These costs are compared to the baseline costs using existing modes of freight transportation. The equation for calculating the cost differential between the cargo airship-enabled freight transportation system and existing freight transportation system costs is given in equation 10.

Cost differential in percent (*D*):

$$D = \left[\frac{TC_A - TC_E}{TC_E} \right] \times 100$$

D : The cost differential between the cargo airship alternative and the existing freight transportation system in percent.

TC_A : Total transportation cost of the cargo airship alternative.

TC_E : Total transportation cost of the existing freight transportation system.

Equation 10 - Cost differential equation.

The cost differential is expressed as a percentage of existing system costs for confidentiality purposes. Calculating the cost savings as a percentage of existing costs still allows the direction and magnitude of changes in the freight system's cost structure to be measured. The use of percentages is not ideal because 10% of $1 and $1,000,000 are two very different numbers however confidentiality requirements dictated the use of this measure. The rules for concluding whether the cargo airship possesses an economic advantage over existing modes of freight transportation are as follows:

1. If $D < 0$, the cargo airship system has a cost advantage relative to the existing system.
2. If $D = 0$, the cargo airship system is equal in cost to the existing system.
3. If $D > 0$, the cargo airship has a cost disadvantage relative to the existing system.

Chapter 5: The East-Side of Lake Winnipeg (ESLW) Case

5.1 Case Introduction

Figure 9 - Map of the ESLW region and the approximate geographic location of its NWC communities. *Modified from*: Canada [computer file]. (no date). St. Catherines, Ontario: Brock University Map Library. Available: Brock University Library Controlled Access http://www.brocku.ca/maplibrary/maps/outline/North_America/PRAIRIES.pdf. Brock University provides this and other maps for free use by the public.

The key characteristics of this region are revisited in this section in order to provide context to the analysis of NWC's operations in the region. The region is located between Lake Winnipeg and the Ontario border from east to west, with Oxford House and Bloodvein at its most northern and southern points respectively (Buhr, Krahn, & Westdal, 2000). A map of the region is illustrated in figure 9. Twelve communities with a combined population of 13,249 (Manitoba Bureau of Statistics, 2008) are located within the region, and none of them are connected to the all-season road network marked by the red lines on the map. In the face of growing problems related to the level of service provided by the existing transportation system in the region, the Province of Manitoba has initiated a plan to construct an all-season road network at a cost of $2.7 billion. In the meantime, the region remains reliant on winter-road trucking and air transport for its freight transportation needs.

Estimates suggest that winter-road trucking accounts for approximately 70% of freight transportation movements into the region (Buhr, Krahn, & Westdal, 2000). The winter-road network in the entire province is 2,200km in length and is constructed annually at a cost of $9 million (Manitoba Infrastructure and Transportation, 2011). Approximately half of the provincial winter road network lies in the ESLW region. The ESLW case study in chapter two showed that climate change is negatively impacting the winter road system. Although the data provided by the NWC show the winter-road season in 2011was 60 days in length, the future viability of the winter road network in the face of climate change remains unclear. Possible scenarios could range from consistent average operating lengths with greater variability from year to year, to a persistently reduced operating season up to and including the complete elimination of this seasonal transportation network.

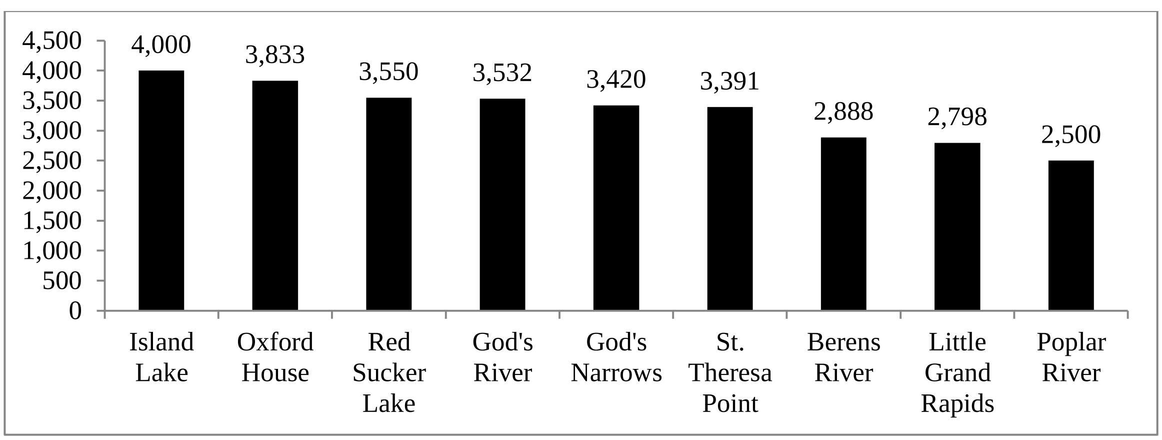

Figure 10 – ESLW community gravel airstrip length in feet. Source: Manitoba Infrastructure and Transportation (2013).

Air transport infrastructure in the region consists of gravel airstrips (Buhr, Krahn, & Westdal, 2000). Figure 10 shows the distribution of airstrip lengths for each of the communities in the ESLW region. Most of the community airstrips are between 3,400 and 4,000 feet in length however Pauingassi and Wasagamack have no airstrip. Relatively low capacity aircraft like the Fairchild Metro 3 and the Bombardier Dash-8 (Perimeter Aviation LP., 2009), capable of carrying three and five metric tonnes of cargo, serve the region. The NWC's data indicate that aircraft are used year-round to re-supply their stores in the region.

5.2 The North West Company's ESLW Operations

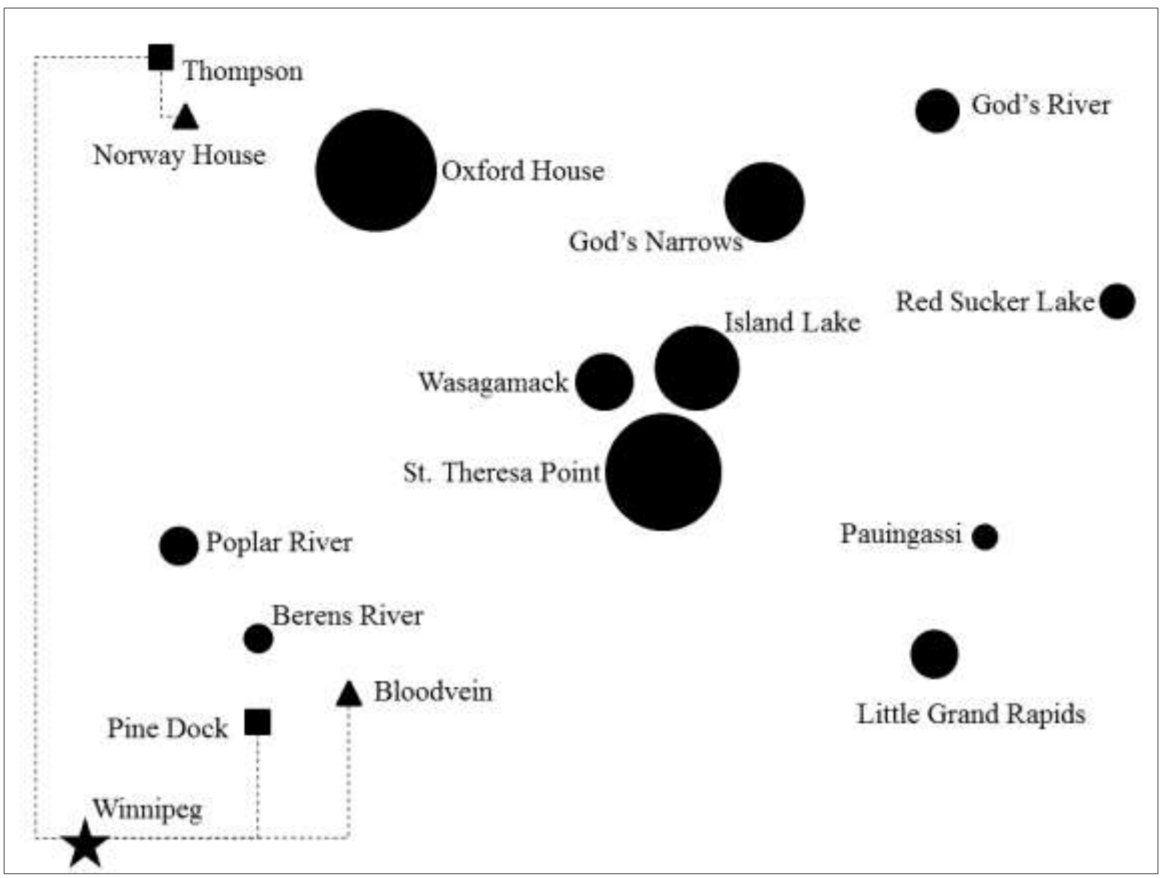

Figure 11 – Conceptual map of NWC's ESLW trading area. Store markers are scaled by freight quantity.

The NWC operates 11 stores in the ESLW that meet the scoping criteria discussed earlier. The company's stores located in Berens River, Poplar River, Little Grand Rapids, Pauingassi, St. Theresa Point, Wasagamack, Red Sucker Lake, Oxford House, Gods Narrows, Gods River, and Island Lake are included in this analysis. Figure 11 is a conceptual map that illustrates the approximate geographic dispersion of the freight origin in Winnipeg, the two trans-shipment points in Pine Dock and Thompson, and the 11 store locations. These are denoted on the map using a star, squares, and circles respectively. This map illustrates the general geographic relationship between the freight origins and destinations and the relative level of demand for freight at each of the store locations. The store markers are scaled in diameter to illustrate the total freight demand of each store relative to the total freight demand of Pauingassi. Norway House and Bloodvein, the two communities marked by triangles, are shown because they represent the end of the all-season road network into the region however none of the NWC's freight passes through these points.

Google Earth (Google, 2013a) and Earth Point (Clark, 2013) software permit the calculation of the perimeter and surface area of the NWC's trading area in the ESLW. The perimeter of the trading area is 896.4km and its surface area totals 38,146km^2. For reference, this is a land area slightly larger than Belgium (30,528km^2) (Central Intelligence Agency, 2013). The size of the trading area, in combination the lack of an all-season road network in the area, illuminates the dual challenges of sustaining the ESLW communities and improving the region's freight transportation system.

Table 5 – Freight quantity data, by mode and by type (t) for all ESLW community stores.

Community	Truck – Food	Truck – GM	Air – Food	Air – GM	Total
Oxford House	236.6	20.5	751.1	110.3	1,118.5
St. Theresa Point	344.3	47.3	567.7	112.5	1,071.8
Island Lake	257.9	20.5	387.2	90.8	756.4
God's Narrows	193.2	26.5	442.2	85.6	747.5
Wasagamack	191.4	14.6	258.7	41.4	506.1
Little Grand Rapids	171.7	0.3	248.4	21.5	441.9
God's River	109.9	4.2	250.4	39.8	404.3
Poplar River	74.7	54.5	209.5	19.2	357.9
Red Sucker Lake	79.9	9.5	151.4	55.2	296.0
Berens River	56.2	1.2	179.6	20.8	257.8
Pauingassi	71.7	8.1	128.5	6.6	214.9
Total	1,787.5	207.2	3,574.7	603.7	6,173.1

Table 5 summarizes the store freight receipts in the 11 stores in the ESLW, with freight receipts functioning as a measure of store-level freight transportation demand. In total, 6,173.1t of freight was shipped to the 11 stores. The average quantity of freight received by these 11 stores is 561.2t, with a maximum of 1,118.5t for the Oxford House store and a minimum of 214.9t for the Pauingassi store. A small number of stores account for the majority of freight demand in the region. The Oxford House and St. Theresa Point stores alone account for 2,190.3t, or 35.5%, of the total freight demand. With the addition of the Island Lake and God's Narrows stores, this proportion reaches 59.8% of the total. Figure 12 is based on the data from table 5 and illustrates the composition of freight by type and by mode for each store. Note that the stores appear in order of total freight quantity received, from highest on the left to lowest on the right.

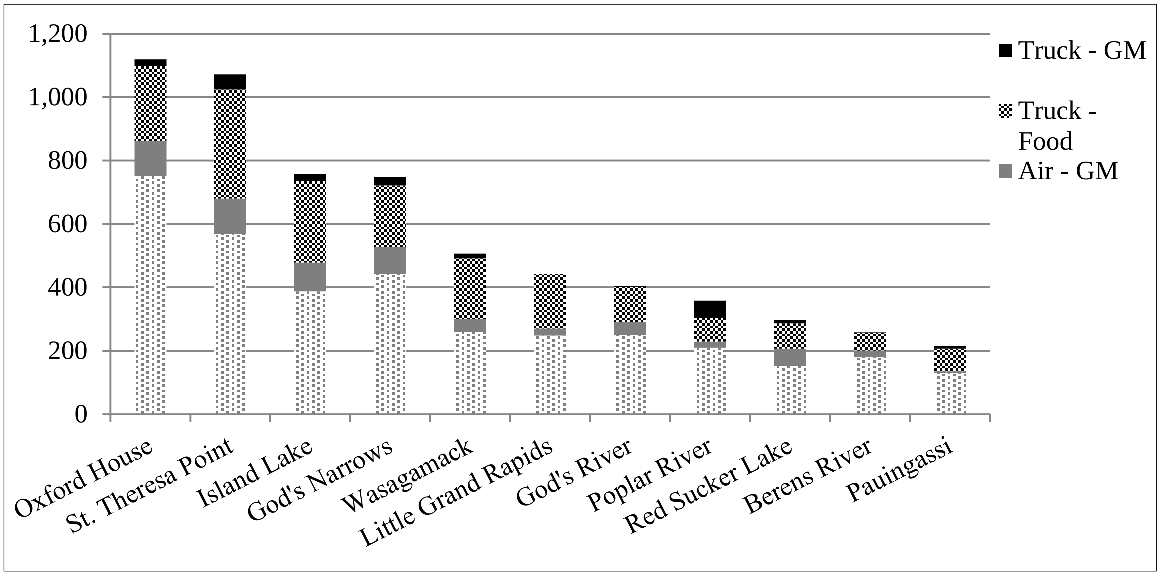

Figure 12 – ESLW freight quantity data, by mode and by type (t) for all community stores.

The mean modal split for all 11 stores is 32.7% truck and 67.3% air, or 181.3t and 379.9t respectively. St Theresa Point receives the greatest quantity of freight by truck (391.6t) while Berens River receives the least (57.4t). The Wasagamack store receives proportionally the most freight by truck, with 40.7% of its freight arriving by that mode, while Berens River receives the least (22.3%). With respect to air transport, the Oxford House store receives the greatest quantity of freight by air (861.4t), and the Pauingassi store receives the least (135.1t). Proportionally, Berens River receives the greatest amount of its freight by air (77.7%) and Wasagamack the least (59.3%).

The split between freight-types is on average 87.2% food and 12.8% GM. At the upper end of the range is the Little Grand Rapids store; 95.1% of the freight this store receives is food. At the low end of the range is the Red Sucker Lake store at 78.1%. In terms of quantities, the Oxford House store receives the largest quantity of food at 987.7t, and the Pauingassi store receives the smallest at 200.2t. St Theresa Point receives the largest quantity of GM freight (159.8t) and Pauingassi the least (14.7t).

Table 6 describes the trans-shipment points that serve as points of entry into the region. These include Winnipeg and the trans-shipment points in Thompson and Pine Dock. The data show that a majority of the freight is routed through the trans-shipment point in Thompson. Note that the data included for Winnipeg only show the flows directly from Winnipeg to the stores and not the freight flows from Winnipeg to the two trans-shipment points.

Table 6 – ESLW freight flows from origins in metric tonnes exclusive of shipments from Winnipeg to Thompson or Pine Dock.

Origin	Truck Food	Truck GM	Air Food	Air GM	Total
Winnipeg - Direct	1,787.5	207.2	6.2	31.6	2,032.5
Pine Dock	766.0	63.7	0.0	0.0	829.7
Thompson	2,802.5	508.4	0.0	0.0	3,310.9

Analysis of the freight flows inclusive of distances allows for the calculation of the metric tonne-kilometers (MTK) for each origin-destination (O-D) pair as a generalized measure of freight transportation production (Jeon, Amekudzi, & Guensler, 2012; Oum, Waters, & Yu, 1999). All MTK figures in the proceeding analyses are presented in 1000's of MTK, rounded to the nearest 100 MTK. Distances for winter road trucking are based on estimates by Buhr, Krahn, & Westdal (2000). It is assumed that all winter road traffic follows the shortest route through Pine Dock because the dataset did not describe winter road truck routing. Google Earth (2012a) is used to calculate the distances by air from the airports in Winnipeg, Thompson, and Pine Dock to each store. The distance from Island Lake to Wasagamack is determined in the same manner.

Table 7 describes the air freight flows that originate from Winnipeg, Thompson, Pine Dock, and the trans-shipment from Island Lake to Wasagamack. Approximately .86 million MTK, or 88.2% of total air freight MTK, originates at Thompson. Approximately

10% of the air MTK flows from Pine Dock, and relatively little is shipped directly from Winnipeg.

Table 7 – ESLW air freight flows by origin. MTK is presented in multiples of 1,000.

Freight Origin	Freight Destination	Quantity (t)	Distance (km)	Air MTK
Winnipeg	God's Narrows	6.5	552	3.6
	St. Theresa Point	7.0	468	3.3
	Island Lake	6.8	476	3.2
	Oxford House	4.8	576	2.8
	Red Sucker Lake	3.8	537	2.0
	God's River	2.5	591	1.5
	Berens River	4.4	275	1.2
	Wasagamack	2.0	474	0.9
			Total – Winnipeg	18.5
Pine Dock	Poplar River	228.7	156	35.7
	Little Grand Rapids	269.9	104	28.1
	Berens River	196.0	83.4	16.3
	Pauingassi	135.1	113	15.3
			Total – Pine Dock	95.4
Thompson	St. Theresa Point	673.2	292	196.6
	Oxford House	856.6	190	162.7
	Island Lake	506.0	297	150.3
	God's Narrows	521.3	255	132.9
	God's River	287.7	264	76.0
	Wasagamack	263.3	282	74.3
	Red Sucker Lake	202.8	330	66.9
			Total – Thompson	859.7
Island Lake	Wasagamack	34.8	18.9	0.7
			Total – Island Lake	0.7
			Total	974.3

Table 8 summarizes the MTK for winter road truck transport. In total, winter road trucking accounts for 1.1 million MTK. This represents 54.1% of the total MTK produced for re-supply in the ESLW. The reason trucking MTK approaches parity with air despite the lower quantities of freight shipped by the former mode is because of the distances involved. The average winter-road trucking distance is 545km, whereas the average distance by air is 317km for all air transport flows. The average distance from Thompson, where the vast majority of air freight is trans-shipped, to each of the stores is 273km, or approximately half of the average winter road trucking distance.

Table 8 – ESLW winter road truck freight flows by quantity (t), distance (km), and MTK for each destination.

Destination	Quantity (t)	Distance (km)	MTK
St. Theresa Point	391.6	567	222.0
Oxford House	257.1	753	193.6
Island Lake	278.4	583	162.3
God's Narrows	219.7	683	150.1
Wasagamack	206.0	577	118.9
God's River	114.1	733	83.6
Little Grand Rapids	172.0	356	61.2
Red Sucker Lake	89.4	679	60.7
Poplar River	129.2	392	50.6
Pauingassi	79.8	372	29.7
Berens River	57.4	296	17.0
		Total	1,149.7

The northern-most stores account for the majority of the total trucking MTK. St. Theresa Point, Oxford House, Island Lake, God’s Narrows, and Wasagamack account for the majority of winter road trucking MTK. These stores are the furthest from Winnipeg and also have the largest demand for freight, the combination of which explains why they account for nearly 74% of all winter-road trucking MTK.

Table 9 lists the total MTK accounted for each store. All stores are listed in rank order from highest total MTK to lowest. The data in table 9 again show that the majority of the freight transportation demand derives from a small number of stores. St. Theresa point accounts for nearly 20% of all MTK alone, while the top four stores together account for nearly 65% of all MTK. Conversely, the bottom four stores combined account for just 12% of all MTK.

Table 9 – MTK by mode and total MTK (1000's) for each ESLW store.

Freight Destination	TS Location	WR MTK	Air MTK	Total MTK
St. Theresa Point	Thompson	222.0	199.9	421.9
Oxford House	Thompson	193.6	165.5	359.1
Island Lake	Thompson	162.3	143.2	305.5
God's Narrows	Thompson	150.1	136.5	286.6
Wasagamack	Thompson	118.9	86.2	205.1
God's River	Thompson	83.6	77.5	161.1
Red Sucker Lake	Thompson	60.7	68.9	129.6
Little Grand Rapids	Pine Dock	61.2	28.1	89.3
Poplar River	Pine Dock	50.6	35.7	86.3
Pauingassi	Pine Dock	29.7	15.3	45.0
Berens River	Pine Dock	17.0	17.5	34.5
			Total MTK	2,124.0

TS Location: The major trans-shipment point from highway to air for each store.
WR MTK: Winter road trucking MTK.
Air MTK: Air transport MTK.

Figure 13 on the following page illustrates the proportion of total transportation costs accounted for by each mode of transportation[9]. Note that highway trucking costs are not included in this analysis and in determining the annual baseline transportation costs in the ESLW because these flows and their corresponding costs are held constant in the alternative scenarios presented later. Although the split between modes in terms of MTK was nearly 50/50 between air and trucking, the relative contribution towards total transportation costs is heavily imbalanced. Air transport accounts for 88.1% of total transportation costs for freight moved into the ESLW. The reason that air accounts for the majority of total transportation costs despite accounting for approximately half of total

[9] The NWC requested that all cost information be kept confidential. Only proportions and percentages will be used in this and subsequent analyses.

MTK is that air freight rates are significantly higher than winter road trucking rates. In addition, air freight rates vary considerably between origin and destination pairs.

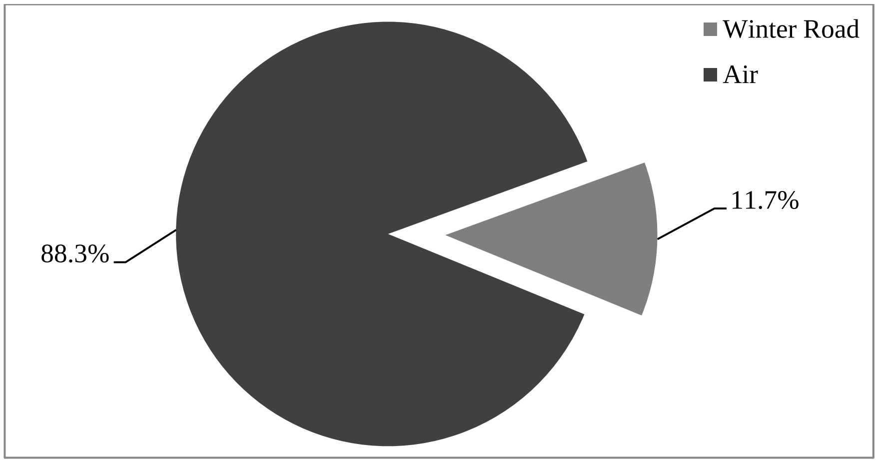

Figure 13 – ESLW proportion of total transportation costs by mode.

Figure 14 on the following page illustrates the magnitude of transportation costs for each mode relative to the average highway trucking cost described in the dataset. The average cost per MTK for each mode is weighted according to each community's level of demand. Communities with greater demand are represented more heavily than communities with lower levels of demand in these weighted average figures. Comparing each mode's average cost per MTK with average highway trucking costs suggests what stores connected to all-season roads may pay for re-supply. The average highway trucking cost is calculated as total highway trucking costs divided by total highway trucking MTK. The average cost per MTK for each mode is computed in a similar fashion. The relative cost per MTK for each mode is computed as the difference between its cost per MTK and the cost per MTK for highway trucking as a percentage of average highway cost per MTK[10].

[10] For example, if the cost per MTK for air transport and highway trucking were 50 cents and 10 cents respectively, then the differential as a percentage of highway trucking costs is 400%.

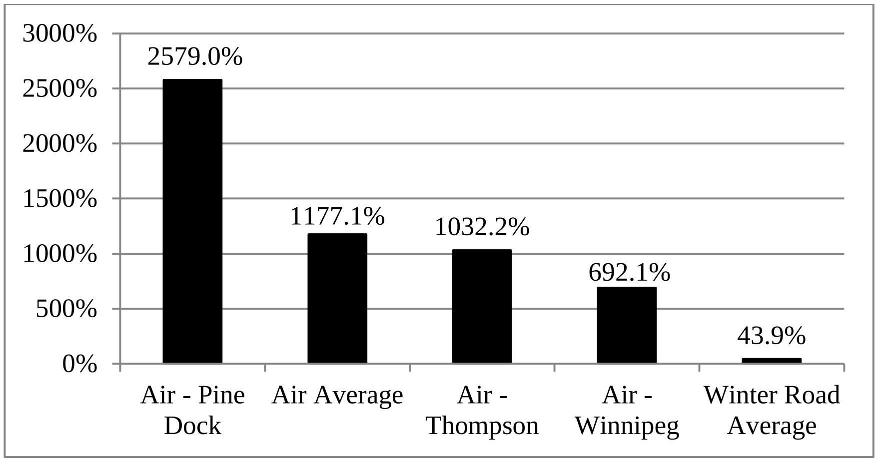

Figure 14 – ESLW weighted average air and winter road trucking $/MTK relative to average highway trucking rates.

Previous estimates suggest that winter road trucking and air transport freight costs throughout the region are 60% and 625% higher than highway trucking (Buhr, Krahn, & Westdal, 2000). The average cost per MTK for winter road trucking and air for the entire region are nearly 50% and twelve times higher than highway trucking respectively. Air freight rates vary widely within modes depending on origin or destination. Air freight rates peak at more than 2,600% higher than average highway trucking rates and winter road trucking peak at 204% higher.

5.3 The Cargo Airship Alternatives

Two cargo airship alternatives are presented in this case. The first alternative provides insight into how the cargo airship might be implemented in the short-term. In this alternative, the cargo airship is used instead of conventional aircraft. Additionally, air freight flows that originate from Winnipeg are instead routed through trans-shipment points at Thompson or Pine Dock. Winter-road trucking flows, on the other hand, remain unchanged. The cost of the first cargo airship alternative is compared to the cost of the existing freight transportation system. The second alternative completely re-structures the freight transportation system in the region. This alternative simulates the consequences of the total loss of the winter road system in Manitoba. The costs of shipping all freight by cargo airship and by conventional aircraft are compared to the cost of the existing system. Note that the cargo airship freight flows go directly to all communities because it does not require an airstrip for landing.

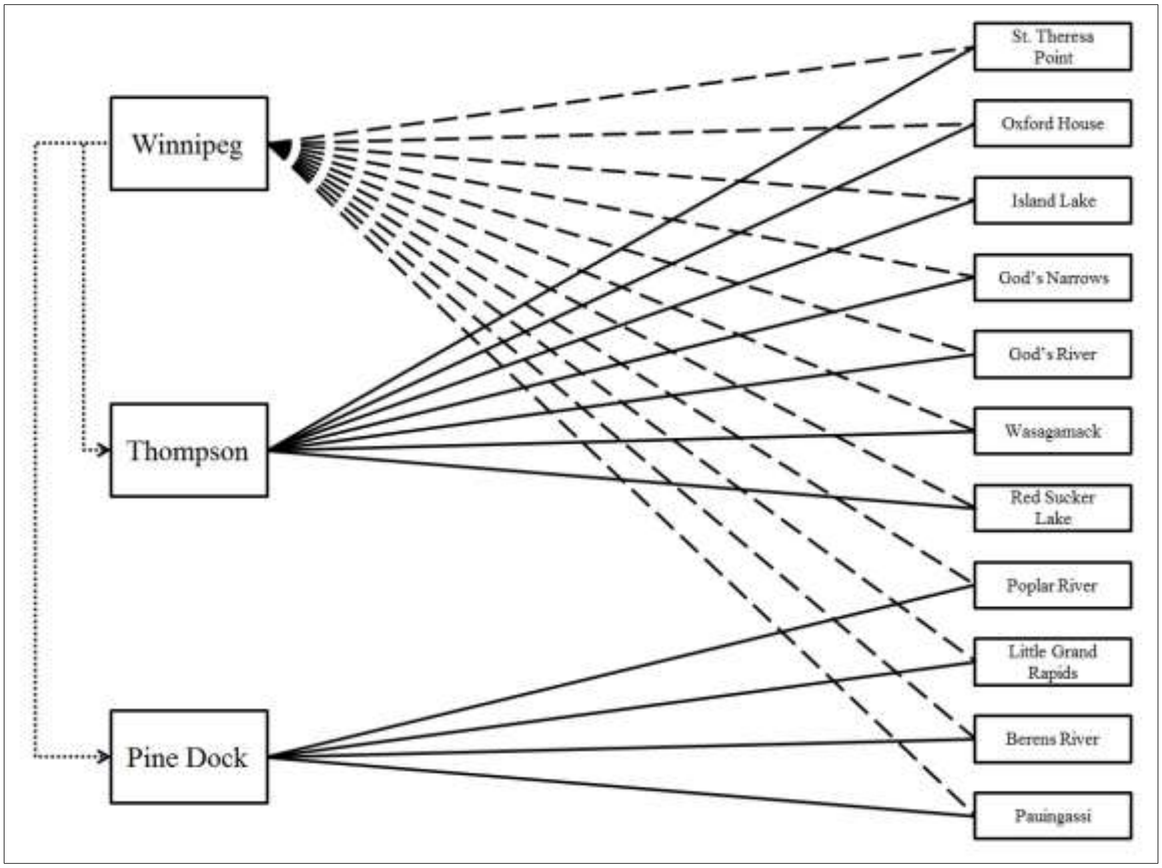

Figure 15 - Diagram of freight flows for ESLW cargo airship alternative 1. The dotted lines connecting Winnipeg to Thompson and Pine Dock represent highway trucking flows, and the long-dashed and solid lines connecting Winnipeg to each community represent winter road trucking and cargo airship freight transportation flows respectively.

The freight flows for the first alternative are illustrated in figure 15. In this scenario, the cargo airship replaces conventional aircraft and winter-road trucking flows remain unchanged. The dotted lines from Winnipeg to Thompson and Pine Dock depict the highway trucking flows. The long-dashed lines between Winnipeg and the 11 ESLW communities represent the winter road trucking freight flows. Finally, the solid lines from

Thompson and Pine Dock to each of the 11 communities represent the cargo airship freight flows. The only change to the ESLW freight transportation network is that the air freight flows from Winnipeg to the ESLW communities are shifted to the trans-shipment points in Thompson and Pine Dock. The changes in highway trucking flows are altered to reflect this.

Table 10 - Cargo airship freight flows for ESLW alternative 1.

Origin	Destination	t	km	MTK
Pine Dock	Poplar River	228.7	156	35.7
	Little Grand Rapids	269.9	104	28.1
	Berens River	200.4	83.4	16.7
	Pauingassi	135.1	113	15.3
	Total Pine Dock	834.1		95.8
Thompson	St. Theresa Point	680.2	292	198.6
	Oxford House	861.3	190	163.6
	Island Lake	478.0	297	142.0
	God's Narrows	527.8	255	134.6
	God's River	290.2	264	76.6
	Wasagamack	300.1	282	84.6
	Red Sucker Lake	206.6	330	68.2
	Total Thompson	3,344.3		868.3
	Total	4,178.4		964.1

t: Annual freight demand in metric tonnes.
km: Distance from origin to destination in kilometres.
MTK: Metric-tonne kilometres.

Table 10 describes the cargo airship freight flows for the first alternative. Total freight transportation costs of this system inclusive of winter road trucking freight flows are assessed to determine the impact of the cargo airship on total annual freight transportation costs. Note that the trans-shipment by helicopter from Island Lake to

Wasagamack is routed instead through Thompson directly to the community Total MTK by cargo airship in this alternative is 0.96 million MTK.

The freight shipped by air from Winnipeg in the baseline scenario is shifted to cargo airship from either Thompson or Pine Dock. Table 11 describes the highway trucking flows that result from this change. Highway distances from Winnipeg to Thompson and Pine Dock are calculated using Google Maps (2013b). In total, 37.8t of freight is transported to trans-shipment points by truck on highways. The majority of this freight is shipped to Thompson.

Table 11 – ESLW alternative 1 Highway trucking flows from Winnipeg to Thompson and Pine Dock.

Origin	Destination	Quantity - t	Distance - km	MTK
Winnipeg	Thompson	33.4	768	25.7
	Pine Dock	4.4	222	1.0
	Total	37.8		26.7

The cost comparison for this alternative is between total system costs. Total system costs include all transportation costs incurred in both the cargo airship system and the baseline system. The cost differential for the first alternative is expressed in equation 11. Note that the cost differentials are calculated for each community and these are then aggregated for the entire region.

Cost difference for cargo airship alternative 1:

$$D = \frac{[HT + WR + CA] - [HT + WR + AC]}{[HT + WR + AC]}$$

HT: Annual Highway Trucking Costs

WR: Annual Winter Road Trucking Costs

CA: Annual Cargo Airship Costs

AC: Annual Conventional Aircraft Costs

Equation 11 - Cost differential equation for ESLW cargo airship alternative 1.

The second alternative illustrates the impacts on annual transportation costs given a loss of winter road trucking. Both the costs of existing aircraft and cargo airships are compared to baseline freight transportation costs to illustrate the impact of the loss of the winter road system. The annual costs of the cargo airship and conventional aircraft are compared to illustrate the cost performance of the former relative to the latter.

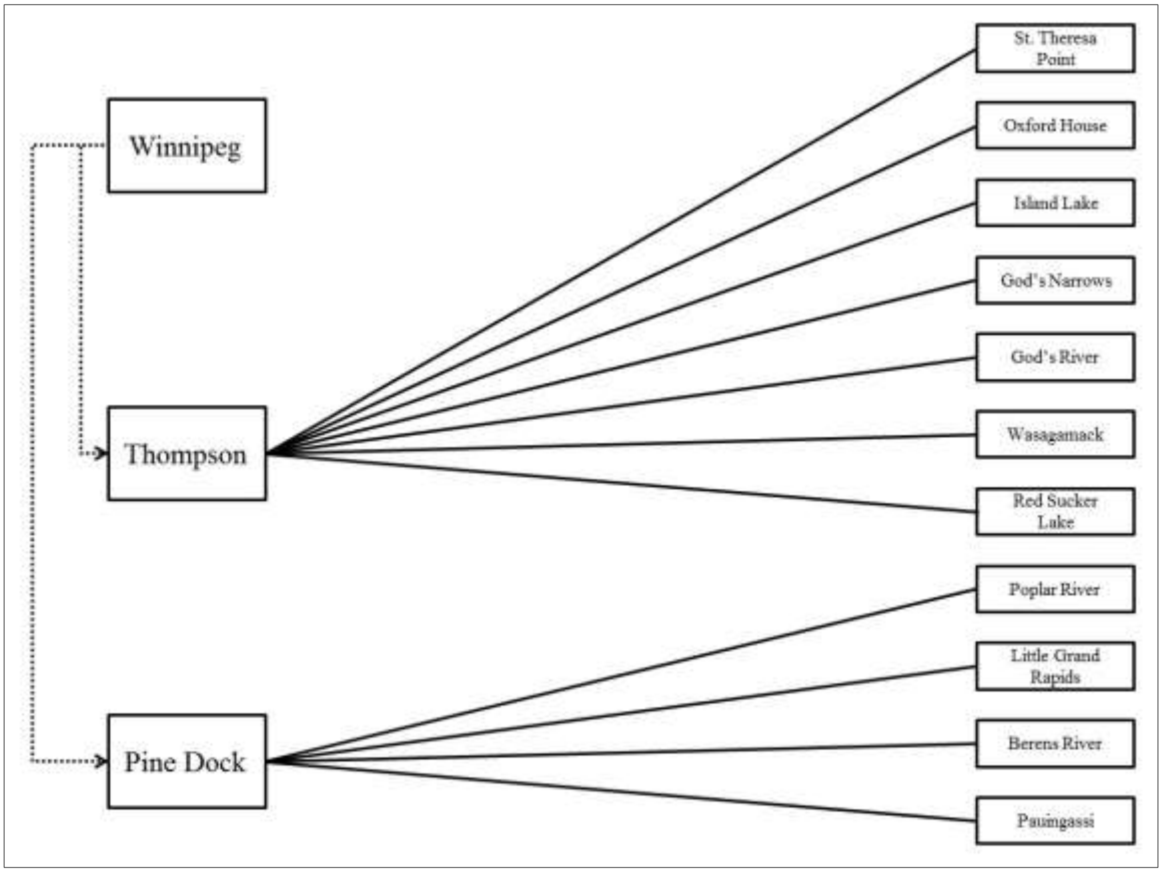

Figure 16 – Diagram of freight flows for ESLW alternative 2. The dotted lines connecting Winnipeg to Thompson and Pine Dock represent highway trucking flows, and the solid lines connecting Winnipeg to each community represent cargo airship freight transportation flows.

The freight flows for alternative 2 are illustrated in figure 16. This alternative includes no direct freight flows from Winnipeg to the ESLW communities by air or by winter road. The dotted lines from Winnipeg to Thompson and Pine Dock depict the incremental highway trucking flows that occur because of the shift from winter road trucking to air. The solid lines between the trans-shipment points in Thompson and Pine

Dock to the 11 ESLW communities depict the air freight flows in this system. The air freight flows apply to conventional aircraft and the cargo airship. The purpose of this comparison is to determine what impact the loss of the winter road system could have on the ESLW community using existing air transport technology and to also determine what the impact might be should cargo airships be adopted.

Table 12 - Air freight flows for both cargo airship and conventional aircraft for ESLW alternative 2.

Origin	Destination	t	km	MTK
Pine Dock	Poplar River	357.9	156	55.8
	Little Grand Rapids	441.9	104	46.0
	Berens River	257.8	83.4	21.5
	Pauingassi	214.9	113	24.3
	Total Pine Dock	1,272.5		147.6
Thompson	St. Theresa Point	1,071.8	292	313.0
	Oxford House	1,118.5	190	212.5
	Island Lake	756.4	297	224.7
	God's Narrows	747.5	255	190.6
	God's River	404.3	264	106.7
	Wasagamack	506.1	282	142.7
	Red Sucker Lake	296.0	330	97.7
	Total Thompson	4,900.6		1,287.9
	Total	6,173.1		1,435.5

t: Annual freight demand in metric tonnes.
km: Distance from origin to destination in kilometres.
MTK: Metric-tonne kilometres.

Table 12 describes the total air freight flows in the second alternative. The freight flows described in table 12 apply to both conventional aircraft and the cargo airship. Only the cost vectors for each type of vehicle change. In total, 1.4 million MTK are required to re-supply the ESLW by air from Thompson and Pine Dock. The freight flows from

Thompson place the greatest demand on the cargo airship. Almost 90% of total MTK originate from there.

The diversion of freight flows from winter road trucking to air requires incremental highway truck transportation to the trans-shipment points in Thompson and Pine Dock. These apply to both conventional aircraft and the cargo airship, and are described in table 13. Note that the costs for these flows are estimated using the baseline highway trucking rates already established in the dataset.

Table 13 – ESLW alternative 2 highway trucking flows from Winnipeg to Thompson and Pine Dock.

Origin	Destination	Quantity - t	Distance - km	MTK
Winnipeg	Thompson	1,556.3	768	1,195.2
	Pine Dock	438.4	222	97.3
	Total	1,994.7		1,292.5

Three cost comparisons are included in this alternative. The first two compare the cost of the cargo airship system and the conventional aircraft system to baseline system costs and the last measures the difference in cost between the cargo airship system and the conventional aircraft system. The equations for these comparisons are expressed in equations 12, 13, and 14.

Cost difference between cargo airship system and baseline system:

$$D = \frac{[\mathrm{HT} + \mathrm{CA}] - [\mathrm{HT} + \mathrm{WR} + \mathrm{AC}]}{[\mathrm{HT} + \mathrm{WR} + \mathrm{AC}]}$$

HT: Annual Highway Trucking Costs
CA: Annual Cargo Airship Costs
WR: Annual Winter Road Trucking Costs
AC: Annual Conventional Aircraft Costs

Equation 12 - Cost difference between ESLW cargo airship system and baseline system in alternative 2.

Cost difference between conventional aircraft system and baseline system:

$$D = \frac{[\mathrm{HT} + \mathrm{AC}] - [\mathrm{HT} + \mathrm{WR} + \mathrm{AC}]}{[\mathrm{HT} + \mathrm{WR} + \mathrm{AC}]}$$

HT: Annual Highway Trucking Costs

AC: Annual Conventional Aircraft Costs

WR: Annual Winter Road Trucking Costs

Equation 13 - Cost difference between conventional aircraft system and baseline system in ESLW alternative 2.

Cost difference between cargo airship system and conventional aircraft system:

$$D = \frac{[\mathrm{HT} + \mathrm{CA}] - [\mathrm{HT} + \mathrm{AC}]}{[\mathrm{HT} + \mathrm{AC}]}$$

HT: Annual Highway Trucking Costs

CA: Annual Cargo Airship Costs

AC: Annual Conventional Aircraft Costs

Equation 14 - Cost difference between conventional aircraft system and baseline system in ESLW alternative 2.

5.4 ESLW Results

ESLW alternative 1 assumes the cargo airship is used instead of conventional aircraft, while winter road trucking flows remain fixed. Serving the ESLW communities in this scenario required a total of 83.6 cargo airship trips and 0.96 million cargo airship MTK. In terms of utilization, the cargo airship is required for a total of 363 block hours and 471.8 occupied hours per year. A summary of the cargo airship transportation requirements is shown in table 14 on the following page.

Table 14 - Summary of cargo airship activity for ESLW alternative 1.

Origin	Destination	t	km	MTK	Trips	BH	OH
Thompson	Oxford House	861.4	190	163.7	17.2	63.6	86.0
	St. Theresa Point	680.2	292	198.6	13.6	72.1	89.8
	God's Narrows	527.8	255	134.6	10.6	49.8	63.6
	Island Lake	478	297	142.0	9.6	51.8	64.3
	Wasagamack	300.1	282	84.6	6.0	31.2	39.0
	God's River	290.2	264	76.6	5.8	28.4	36.0
	Red Sucker Lake	206.6	330	68.2	4.1	24.2	29.5
	Total - Thompson	3,344.3		868.3	66.9	321.1	408.2
Pine Dock	Little Grand Rapids	269.9	104	28.1	5.4	12.4	19.4
	Poplar River	228.7	156	35.7	4.6	14.7	20.7
	Berens River	200.4	83.4	16.7	4.0	8.0	13.2
	Pauingassi	135.1	113	15.3	2.7	6.8	10.3
	Total – Pine Dock	834.1		95.8	16.7	41.9	63.6
	Total	4,178.4		964.1	83.6	363.0	471.8

t: Annual freight quantity in T.
km: Trip distance between origin and destination pair.
Trips: Annual cargo airship trips.
MTK: Annual cargo airship MTK.
BH: Annual cargo airship block hours.
OH: Annual cargo airship occupied hours.

Results for the cost comparison conducted for ESLW alternative 1 are described in table 15. The results from this analysis are also illustrated in figure 17 on the region's conceptual map on page 70. The weighted average impact of the cargo airship in this scenario is a reduction in total annual freight transportation costs of 31.6%. Pauingassi experiences the largest cost reduction (55.2%) while Oxford House experiences the least (18.4%) in percentages. St. Theresa Point and God's River experience the largest and smallest cost reductions in dollar terms respectively.

Table 15 - Cost comparison results for ESLW alternative 1.

Trans-ship	Community	HWY t	CA t	WR t	*D*
Thompson	Oxford House	861.4	861.4	257.1	-18.4%
	St. Theresa Point	680.2	680.2	391.6	-33.2%
	God's Narrows	527.8	527.8	219.7	-19.8%
	Island Lake	478	478	278.4	-32.2%
	Wasagamack	300.1	300.1	206	-36.6%
	God's River	290.2	290.2	114.1	-21.4%
	Red Sucker Lake	206.6	206.6	89.4	-29.3%
	Total - Thompson				
Pine Dock	Little Grand Rapids	269.9	269.9	172	-47.3%
	Poplar River	228.7	228.7	129.2	-47.9%
	Berens River	200.4	200.4	57.4	-39.9%
	Pauingassi	135.1	135.1	79.8	-55.2%
	Total – Pine Dock				
	Total	4178.4	4178.4	1994.7	-31.6%

Trans-ship: Trans-shipment point between highway trucking and the cargo airship.
HWY t: Highway trucking freight quantity (T).
CA t: Cargo airship freight quantity (T).
WR t: Winter road freight quantity (T).
D: Cost difference between ESLW 1 and the baseline ESLW system.

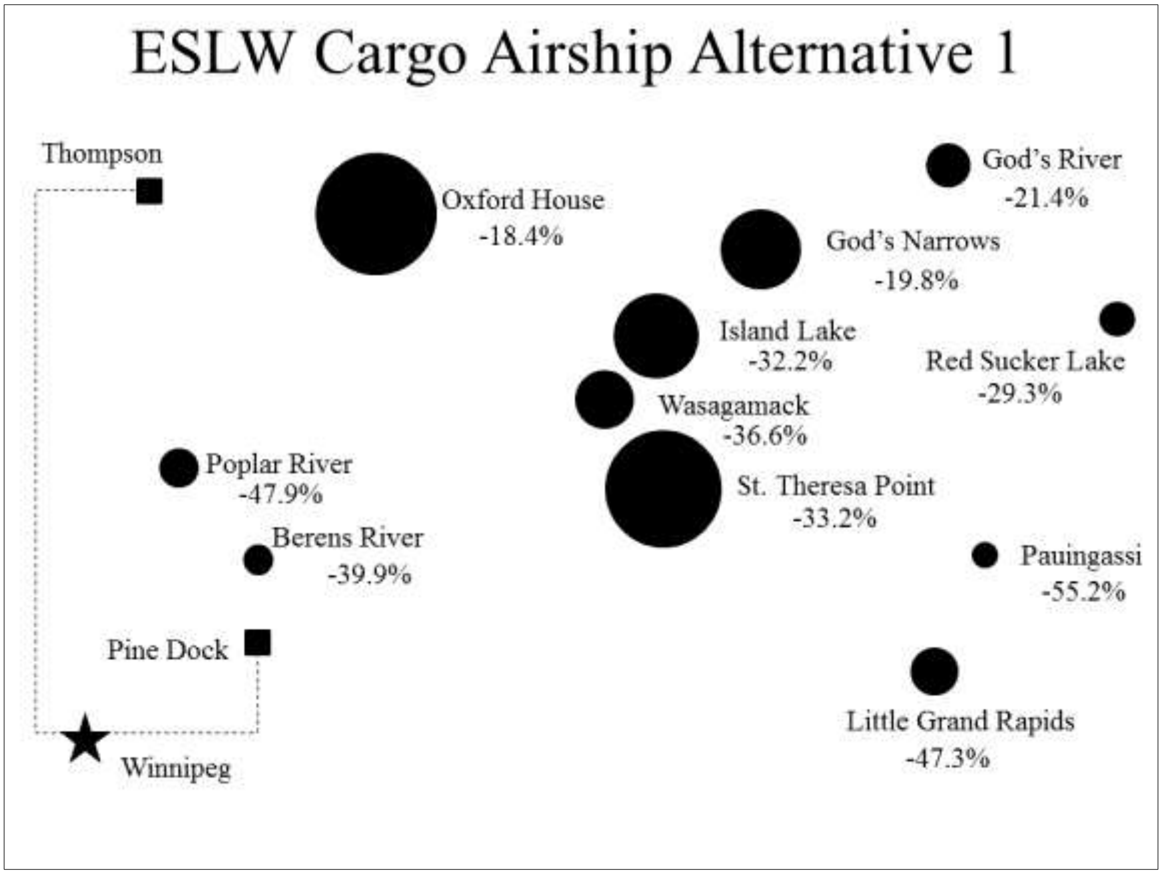

Figure 17 - Map of results from ESLW cargo airship alternative 1. The percentages indicate the proportional cost differential between the baseline ESLW freight transportation system costs and cargo airship alternative 1 in which the cargo airship replaces conventional aircraft and winter road trucking flows remain fixed.

Scenario 2 assumes all freight is shipped via cargo airship and that winter road trucking is no longer used. The cargo airship freight flows for this alternative are described in table 16. All 6,173.1t of freight is carried to the ESLW communities from the trans-shipment points in Thompson and Pine Dock. This calls for a total of 1.4 million cargo airship MTK, 539.7 block hours, and 700.4 occupied hours over 539.7 trips annually. Nearly half of the cargo airship utilization is accounted for by the freight flows to Oxford House, St. Theresa Point, and Island Lake. On the other hand, the four communities served from Pine Dock together account for fewer cargo airship operating and block hours than that required to serve Island Lake.

Table 16 - Summary of cargo airship activity for ESLW alternative 2.

Origin	Destination	t	km	MTK	Trips	BH	OH
Thompson	Oxford House	1,118.5	190	212.5	22.4	82.9	112.0
	St. Theresa Point	1,071.8	292	313	21.4	113.4	141.2
	God's Narrows	747.5	255	190.6	15	70.5	90.0
	Island Lake	756.4	297	224.7	15.1	81.5	101.2
	Wasagamack	506.1	282	142.7	10.1	52.5	65.7
	God's River	404.3	264	106.7	8.1	39.7	50.2
	Red Sucker Lake	296	330	97.7	5.9	34.8	42.5
	Total Thompson	4,900.6		1,287.9	98	475.3	602.8
Pine Dock	Little Grand Rapids	441.9	104	46	8.8	20.2	31.7
	Poplar River	357.9	156	55.8	7.2	23.0	32.4
	Berens River	257.8	83.4	21.5	5.2	10.4	17.2
	Pauingassi	214.9	113	24.3	4.3	10.8	16.3
	Total Pine Dock	1,272.5		147.6	25.5	64.4	97.6
	Total	6,173.1		1,435.5	123.5	539.7	700.4

t: Annual freight quantity in metric tonnes.
km: Trip distance between origin and destination pair.
Trips: Annual cargo airship trips.
MTK: Annual cargo airship MTK (1,000's).
BH: Annual cargo airship block hours.
OH: Annual cargo airship occupied hours.

The cost comparison results are shown in table 17 and are illustrated in figure 18 on page 73. Note that there are three cost comparisons conducted in this scenario. D_1 is the cost comparison between the cargo airship system annual costs and the baseline. Again, all communities experience a decrease in annual transportation costs of an average 12.5%. D_2 is the cost differential between system costs if only conventional aircraft are used and the cargo airship system costs. The cargo airship system is in total 35.2% less costly than if only conventional aircraft were used. This is confirmed with D_3, the cost differential between a conventional aircraft-only system and the baseline. Communities in the ESLW would experience a 35.1% increase in annual transportation costs on average if winter road trucking were no longer available and only conventional aircraft were used.

Table 17 - Cost comparison results for ESLW alternative 2.

Trans-ship	Community	HWY t	CA t	D_1	D_2	D_3
Thompson	Oxford House	1,118.5	1,118.5	-5.0%	-19.7%	18.2%
	St. Theresa Point	1,071.8	1,071.8	-9.1%	-36.7%	43.5%
	God's Narrows	747.5	747.5	-2.3%	-22.0%	25.2%
	Island Lake	756.4	756.4	-6.3%	-35.5%	45.3%
	Wasagamack	506.1	506.1	-10.8%	-37.4%	42.6%
	God's River	404.3	404.3	-3.1%	-23.4%	26.5%
	Red Sucker Lake	296	296	-11.2%	-32.0%	30.6%
Pine Dock	Little Grand Rapids	441.9	441.9	-30.7%	-52.8%	46.9%
	Poplar River	357.9	357.9	-36.3%	-54.0%	38.6%
	Berens River	257.8	257.8	-28.6%	-41.6%	22.3%
	Pauingassi	214.9	214.9	-43.5%	-60.9%	44.5%
	Total	6,173.1	6,173.1	-12.5%	-35.2%	35.1%

Trans-ship: Trans-shipment point between highway trucking and the cargo airship.
HWY t: Highway trucking freight quantity (t).
CA t: Cargo airship freight quantity (t).
D_1: Cost difference between ESLW 2 and the baseline ESLW system.
D_2: Cost difference between ESLW 2 and the conventional aircraft system.
D_3: Cost difference between the conventional aircraft system and the baseline ESLW system.

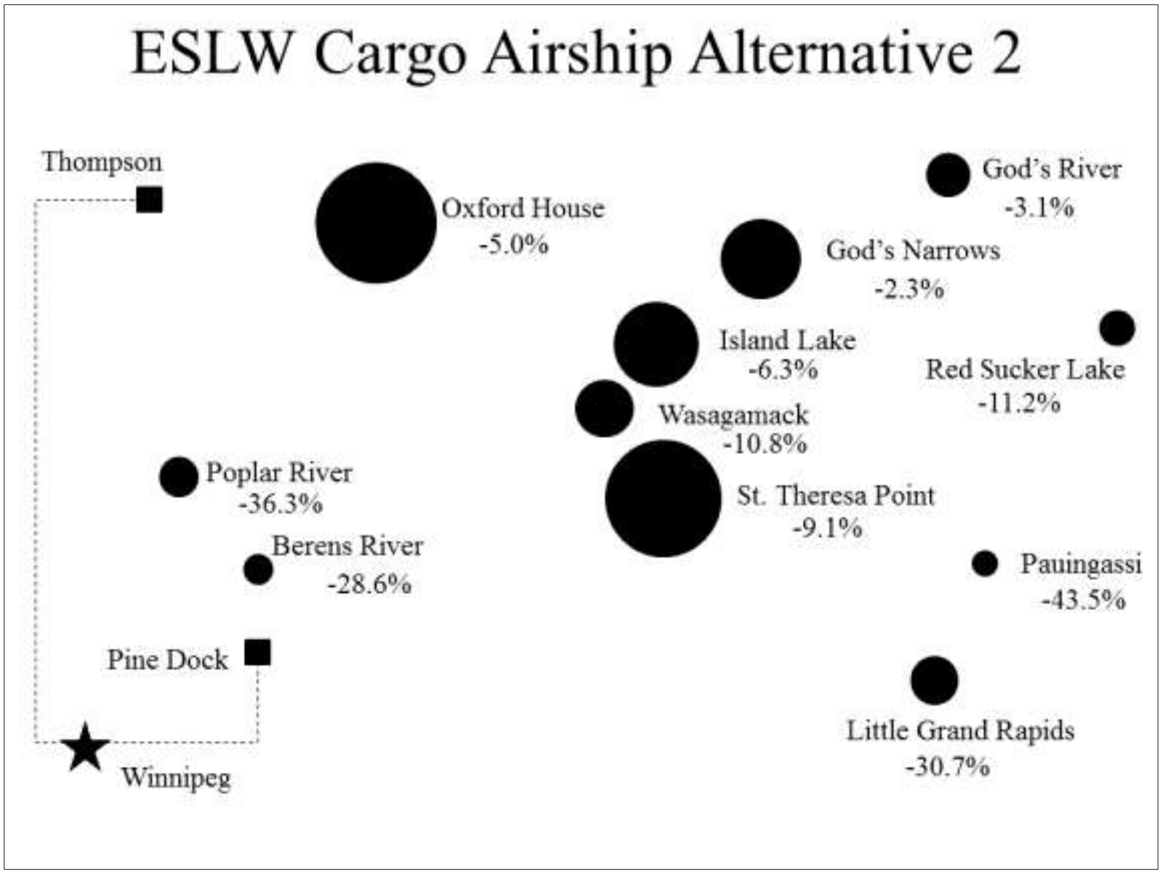

Figure 18 - Map of results from ESLW cargo airship alternative 2.The percentages indicate the proportional cost differential between the baseline ESLW freight transportation system costs and cargo airship alternative 2 in which all freight is carried by cargo airship only. The figures shown in this map are for D_1 shown in table 39.

The within-case comparison between ESLW alternatives 1 and 2 is summarized in table 18 on the following page. The purpose of this analysis is to determine the cost differential between the cargo airship-only freight transportation system and the cargo airship system that includes winter road trucking when considering direct transportation costs exclusively. The findings from this analysis show the annual transportation cost savings from the system with winter road trucking are 19.1% greater than the savings from the alternative without. Differences of approximately 25% are observed in St. Theresa Point, Island Lake, and Wasagamack while transportation costs in the remaining communities rise by between 11% and 18% when winter road trucking is removed from the cargo airship system. In summary, the lowest costs are achieved in the ESLW region when the cargo airship is used in conjunction with winter road trucking.

Table 18 - Cost savings (vs. baseline) comparison between ESLW alternative 1 and ESLW alternative 2.

Trans-ship	Community	*D* ESLW 1	*D* ESLW 2	Difference
Thompson	Oxford House	-18.4%	-5.0%	13.4%
	St. Theresa Point	-33.2%	-9.1%	24.1%
	God's Narrows	-19.8%	-2.3%	17.5%
	Island Lake	-32.2%	-6.3%	25.9%
	Wasagamack	-36.6%	-10.8%	25.8%
	God's River	-21.4%	-3.1%	18.3%
	Red Sucker Lake	-29.3%	-11.2%	18.1%
Pine Dock	Little Grand Rapids	-47.3%	-30.7%	16.6%
	Poplar River	-47.9%	-36.3%	11.5%
	Berens River	-39.9%	-28.6%	11.3%
	Pauingassi	-55.2%	-43.5%	11.7%
	Total	-31.6%	-12.5%	19.1%

Chapter 6: The Northwest Ontario (NWON) Case

6.1 Case Introduction

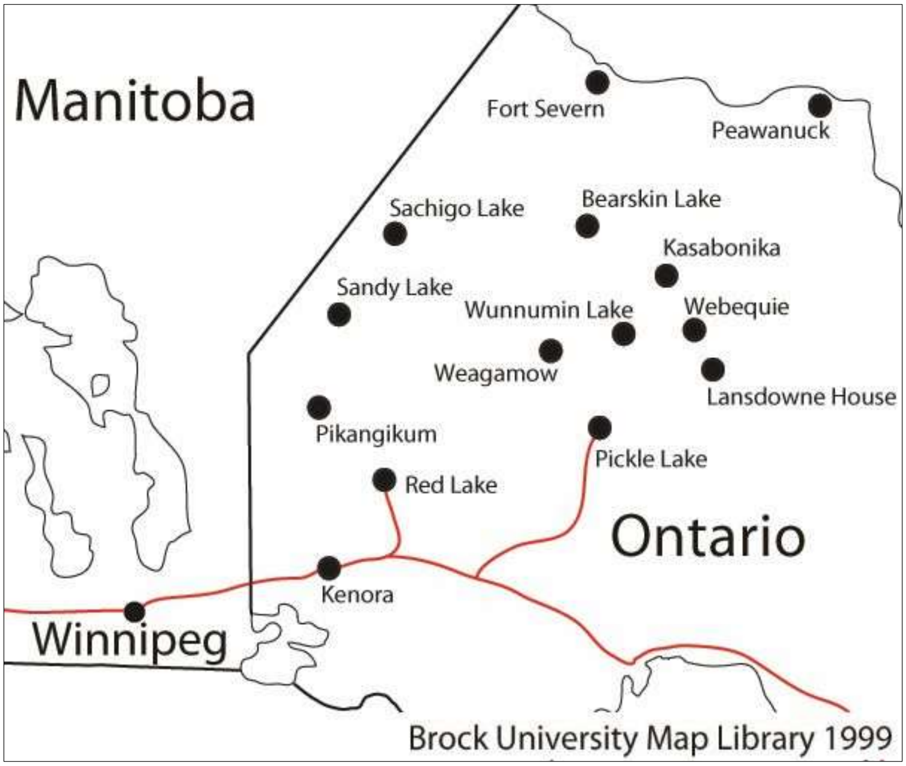

Figure 19 - Map of the NWON region and the approximate geographic location of its NWC communities. *Modified from*: Canada [computer file]. (no date). St. Catherines, Ontario: Brock University Map Library. Available: Brock University Library Controlled Access http://www.brocku.ca/maplibrary/maps/outline/North_America/canada.pdf. Brock University provides this and other maps for free use by the public.

The NWON region is bordered by Sandy Lake to the west, Webequie to the east, Fort Severn to the north, and Pikangikum to the south. This is illustrated in the NWON map in figure 19. Boreal forest covers the southern portion of the region (Thompson et al., 2007) and the northern portion is classified as subarctic barrens (Ontario Ministry of Natural Resources, 2013). The terrain throughout the region is rugged, and its features and obstacles include muskeg, numerous lakes, and dense forests.

The NWC operates stores in 11 of the NWON region. Their stores located in Sandy Lake, Pikangikum, Webequie, Wunnumin Lake, Kasabonika, Weagamow Lake, Sachigo

Lake, Fort Severn, Lansdowne House, Bearskin Lake, and Peawanuck are included in this analysis. The population figures for each of these communities are presented below in table 19.

Table 19 - NWON community population data. Source: Statistics Canada (2006).

Community	Population	Community	Population
Pikangikum	2,100	Bearskin Lake	459
Sandy Lake	1,843	Sachigo Lake	450
Weagamow Lake	700	Fort Severn	401
Kasabonika	681	Lansdowne House	265
Webequie	614	Peawanuck	221
Wunnumin Lake	487		
		Total	8,221

The Province of Ontario constructs more than 3,000 KM of winter roads at a cost of $4.5 million each year (Queen's Printer for Ontario, 2013). A map of the province's winter road network (not shown) indicates that the majority of this seasonal infrastructure is built in the NWON region (Ontario Ministry of Northern Development and Mines, 2103). As is the case in the ESLW, the NWON's winter road network is negatively affected by a warming climate. A recent report indicates that re-supply has been hampered by winter road service disruption, and residents have begun lobbying for the construction of an all-season road network citing concerns over the high cost of air re-supply and the winter road network's current low reliability (CBC News, 2013). Unlike the ESLW, however, neither the Province of Ontario nor the federal government have taken any action to construct all-season road infrastructure.

Each of the 11 locations possesses a community airstrip. The lengths of these airstrips are presented in figure 20. As is the case in the ESLW, the airstrips in the NWON are relatively short. The airlines serving these communities operate aircraft like the

Bombardier Dash-8 300 and the Hawker Siddeley 748 (Wasaya Airways, 2013; Air Creebec, 2013). These aircraft are capable of carrying payloads upwards of 5 T.

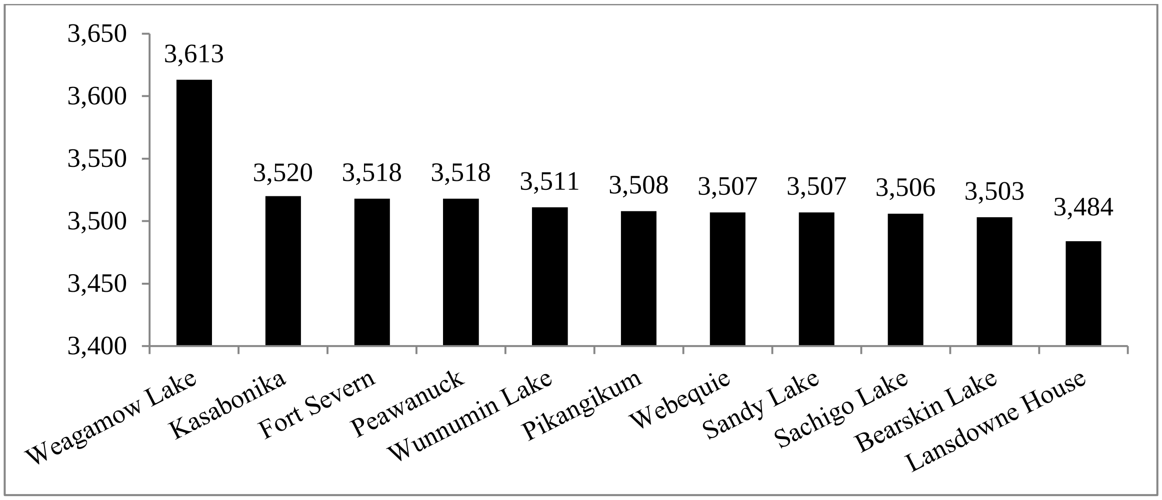

Figure 20 – NWON Community airstrip length in feet. Sources: Nav Canada (2013), Airplane Manager (2013).

6.2 The North West Company's NWON Operations

The 11 NWC stores are illustrated in figure 21, a conceptual map of the NWON region. The star marking Winnipeg denotes its role as a freight origin and the trans-shipment points in Red Lake and Pickle Lake are denoted by squares. The dotted lines illustrate the end of the road network into the region. The diameters of the store markers are scaled to each store's total freight demand relative to the total freight demand in Peawanuck. Google Earth (Google, 2013a) and Earth Point (Clark, 2013) software is used to calculate the perimeter and surface area of the NWC's regional trading area. NWON trading area is 117,537km^2. Perimeter is 1705.6km. For reference, this is an area slightly larger than Bulgaria (Central Intelligence Agency, 2013), and it is approximately 50% larger than the ESLW.

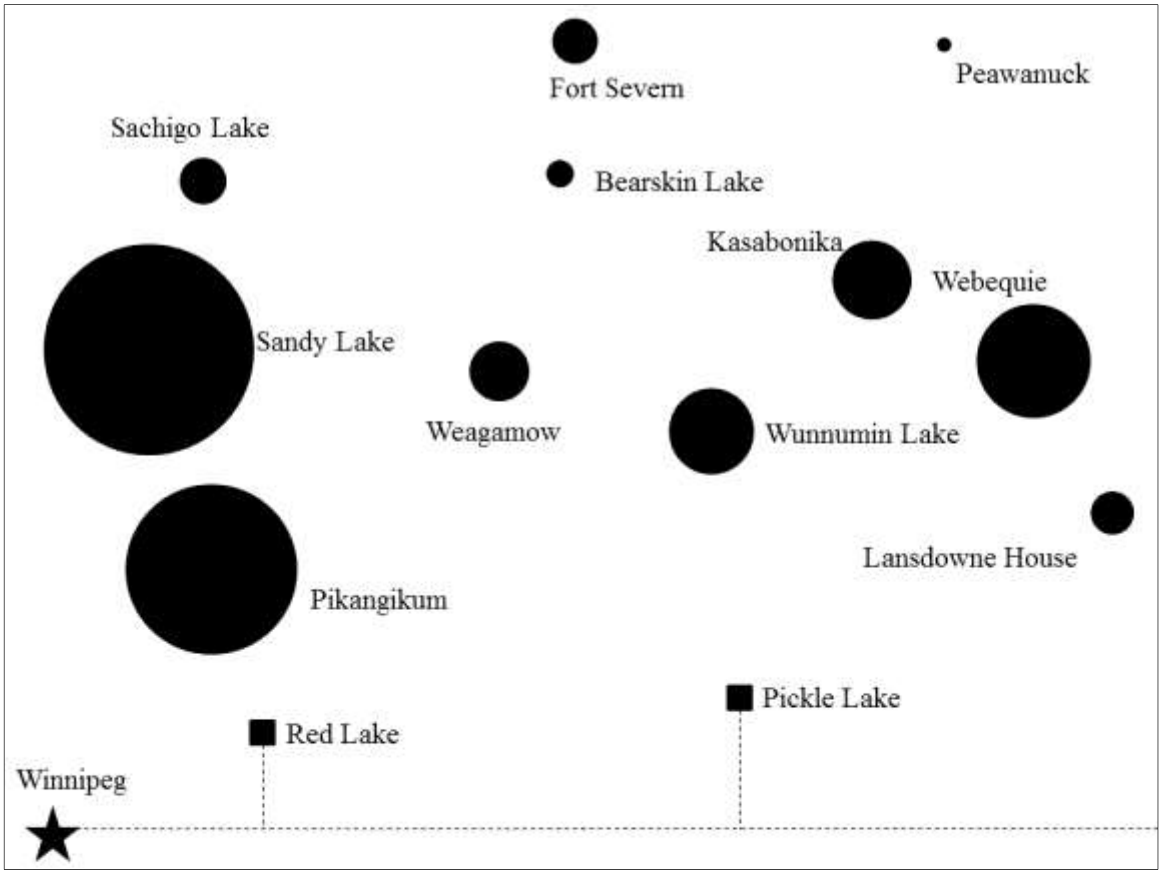

Figure 21 - Conceptual map of the NWC's NWON trading area. Store markers are scaled by total freight quantity (t).

Table 20 – NWON freight quantity data, by mode and by type (t) for all community stores.

Community	Truck - Food	Truck - GM	Air - Food	Air - GM	Total
Sandy Lake	178.1	25.9	795.5	85.8	1,085.3
Pikangikum	169.0	22.1	608.2	78.4	877.7
Webequie	0.0	0.0	534.8	47.4	582.2
Wunnumin Lake	28.8	4.1	353.4	43.9	430.2
Kasabonika	0.0	0.0	358.1	42.4	400.5
Weagamow Lake	47.9	12.5	212.1	20.3	292.9
Sachigo Lake	32.3	6.8	166.0	21.1	226.1
Fort Severn	54.3	9.0	136.8	18.7	218.8
Lansdowne House	0.0	0.0	200.5	9.8	210.3
Bearskin Lake	0.0	0.0	114.9	11.7	126.6
Peawanuck	0.0	0.0	41.4	18.1	59.5
Total	510.4	80.4	3,521.7	397.6	4,510.1

Table 20 summarizes the freight demand by type and by the mode of transport used for delivery for each of the 11 stores. Figure 22 on the following page is based on the data in table 20. This illustrates the total quantity of freight demanded by each store, again by type and by mode. The stores in both table 20 and figure 22 are presented in order of total freight demand, from highest to lowest.

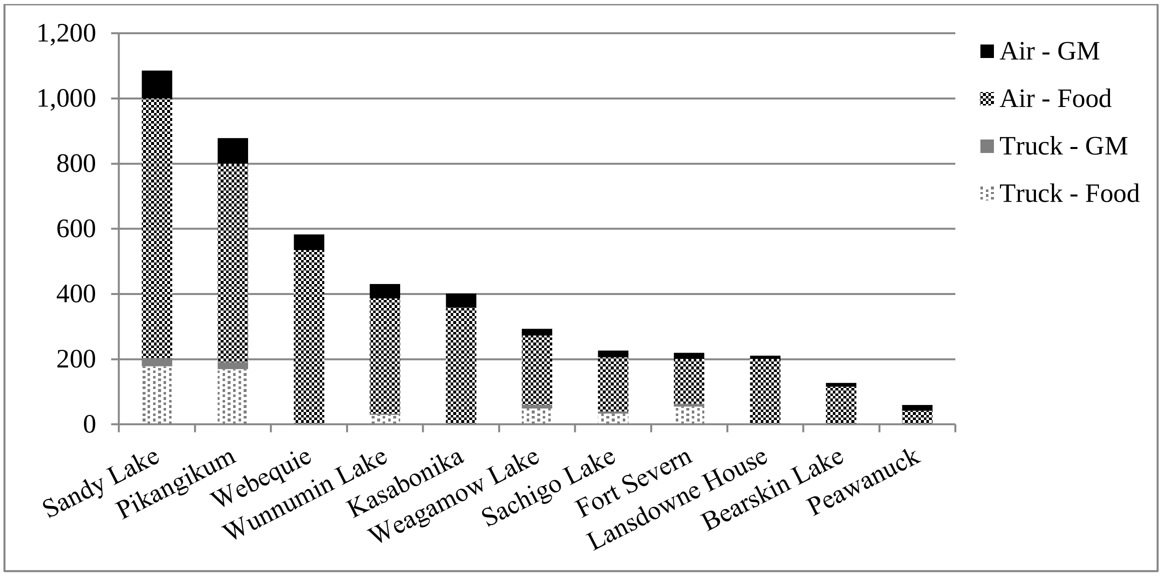

Figure 22 – NWON freight quantity data, by mode and by type (t) for all community stores.

In terms of modal usage, it is of interest that a number of the stores rely exclusively on air transport for re-supply despite the fact that all of the NWON stores are located in communities that are connected to the province's winter road network. It is unclear why no records exist of shipments via truck over winter roads to Webequie, Kasabonika, Sachigo Lake, Bearskin Lake, and Peawanuck. In comparison with the ESLW, relatively little is spent per kilometer in the NWON on winter road construction. The lack of winter road trucking data could be because the roads are of poor quality and therefore impassable. Indeed, the poor condition of the winter road network in the NWON has been noted by shippers in the region (Pokrupa, 2007). The proceeding analyses summarize the data as-is with the acknowledgement that the dataset may be incomplete.

For the stores that use both modes of transportation, the mean modal split is 19.2% winter-road trucking and 80.8% air transport. Six of the stores use winter-road trucking.

Of those, Sandy Lake received the most freight by winter-road (204t) and Wunnumin Lake the least (32.9t). Fort Severn receives the greatest proportion of its freight by winter-road (28.9%) while Wunnumin receives the least (7.6%). Across all stores, Sandy Lake receives the largest quantity of freight by air (881.3t) and Peawanuck receives the least (59.5t). For the stores that use both modes, Wunnumin receives the greatest proportion of its total freight by air (92.4%) and Fort Severn the least (71.1%). In total, 3,919.3t (86.9%) of freight is transported by air and 590.8t (13.1%) is transported by trucks over winter roads.

The average freight-type split is 88% food and 12% GM, or 366.6t of food and 43.5t of GM. Sandy Lake receives the greatest total amount of food at 973.6t while Peawanuck receives the least with 41.4t. Sandy Lake also receives the greatest quantity of GM with 111.7t while Lansdown House receives the least at 9.8t. Lansdowne House has the highest amount of food freight as a proportion of its total freight receipts (95.3%) while Peawanuck has the least (69.6%). Overall, 4,032.1t of food (89.4%) and 478t (10.6%) of GM are shipped into the NWON region.

Analysis of the freight origins provides further evidence that the NWC actively seeks to minimize the use of air transport. Table 21 on the following page presents the summarized data for each freight origin exclusive of highway truck flows. All of the air freight flows originate ultimately from Winnipeg. Freight is trans-shipped at either Red Lake or Pickle Lake from highway trucking to air. As the data shows, the lowest-cost mode of transport is used for as much of the distance between the NWC's distribution centre in Winnipeg and the NWON stores as possible, and air is used where the roads end.

Table 21 – NWON freight flows from origins, not including shipments from Winnipeg to Red Lake or Pickle Lake, in t.

Origin	Truck Food	Truck GM	Air Food	Air GM	Total
Winnipeg - Direct	510.4	80.4	0.0	0.0	590.8
Red Lake	0.0	0.0	1,569.7	185.4	1,755.0
Pickle Lake	0.0	0.0	1,952.0	212.3	2,164.3

Analysis of the freight flows between O-D pairs inclusive of distance data provides further insight into the NWC's re-supply operations in the region. MTK between O-D pairs is again used as a measure of freight transportation production in the region. The highway portions of the the total trucking distances are determined using Google Maps (2012b). Google Earth (2012a) and the Ontario Ministry of Northern Development and Mines' winter road map (2013) are used to calculate the distances for the winter-road portion. Google Earth (2012b) is also used to calculate the great circle distances between Red Lake and Pickle Lake and the stores re-supplied from each trans-shipment point. All MTK figures are again presented in 1000's of MTK, rounded to the nearest 100 MTK.

The air freight flows are summarized in table 22 on the following page. Air transport accounts for approximately 0.87 million MTK in total. The majority of the air freight flows in terms of MTK (63.4%) originate in Pickle Lake. The remainder (36.4%) originates in Red Lake. Pickle Lake serves a greater number of stores that in total combine for a greater quantity of freight than those served from Red Lake. In addition, the average distances between Pickle Lake and the stores it serves are higher.

Winter-road trucking flows are summarized in table 23, also on the following page. Six of the NWON stores received freight by truck during the winter. Trucking accounts for 0.51 million MTK, or approximately 37% of total MTK. Although the average trucking distances are significantly higher than the average air distances in the region, a relatively low proportion of the total freight is transported by truck. The distances shown here include the highway portion of the total route distance. On average, the portion of the route that traverses over the winter road network is 381km in length.

Table 22 – NWON air freight flows by origin. MTK is presented in multiples of 1,000.

Origin	Destination	Quantity (t)	Distance (km)	MTK
Pickle Lake	Webequie	582.2	257	149.6
	Kasabonika	400.5	255	102.1
	Severn	155.5	536	83.3
	Wunnumin Lake	397.3	173	68.7
	Weagamow	232.4	183	42.5
	Lansdowne House	210.3	178	37.4
	Bearskin Lake	126.6	286	36.2
	Peawanuck	59.5	506	30.1
			Total – Pickle Lake	550.1
Red Lake	Sandy Lake	881.3	224	197.4
	Sachigo Lake	187.1	332	62.1
	Pikangikum	686.6	84.7	58.2
			Total – Red Lake	317.7
			Total	867.6

Table 23 – NWON winter road truck freight flows. Includes quantities (t), distances (km), and truck MTK for each destination.

Origin	Destination	Quantity (t)	Distance (km)	MTK
Winnipeg	Sandy Lake	204.0	800.7	163.3
	Pikangikum	191.1	572.7	109.5
	Severn	63.3	1,514	95.8
	Weagamow	60.5	986	59.6
	Sachigo Lake	39.0	1,122	43.8
	Wunnumin Lake	32.9	1,120	36.8
	Total	590.8		508.8

The air and truck MTK accounted for by each store are summarized in table 24. The stores appear in order of total MTK, from highest to lowest. The Sandy Lake store alone accounts for 26.2% of the total MTK, while the top five stores combined account for nearly 70%. The bottom five stores together account for 22.6% of total MTK, slightly less than the Sandy Lake store.

Table 24 - MTK by mode and total MTK (1,000's) for each ESLW store, in order from highest total MTK to lowest.

Freight Destination	WR MTK	Air MTK	Total MTK
Sandy Lake	163.3	197.4	360.7
Webequie	0.0	149.6	149.6
Pikangikum	109.5	58.2	167.7
Kasabonika	0.0	102.1	102.1
Severn	95.8	83.3	179.1
Wunnumin Lake	36.8	68.7	105.5
Sachigo Lake	43.8	62.1	105.9
Weagamow Lake	59.6	42.5	102.1
Lansdowne House	0.0	37.4	37.4
Bearskin Lake	0.0	36.2	36.2
Peawanuck	0.0	30.1	30.1
		Total MTK	1,376.4

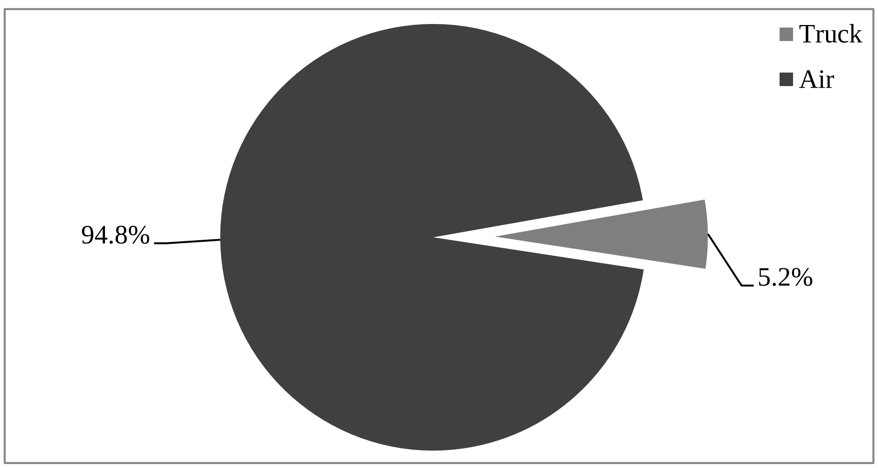

Figure 23- NWON proportion of total transportation costs by mode exclusive of highway trucking.

Figure 23 illustrates the proportion of total transportation costs accounted for by each mode. Because of the heavy reliance on air transport in the region, it is expected that air transport costs account for the large majority of total transportation costs. Indeed, air transport accounts for 94.8% of the total transportation costs incurred. Trucking accounts for approximately a third of all MTK, but accounts for only 5.2% of total costs. Note that these are exclusive of the highway trucking freight flows between Winnipeg and the trans-shipment points. The relationship between the total MTK produced by each mode and each mode's proportion of total transportation costs suggests that air freight rates are significantly higher than trucking rates in the region.

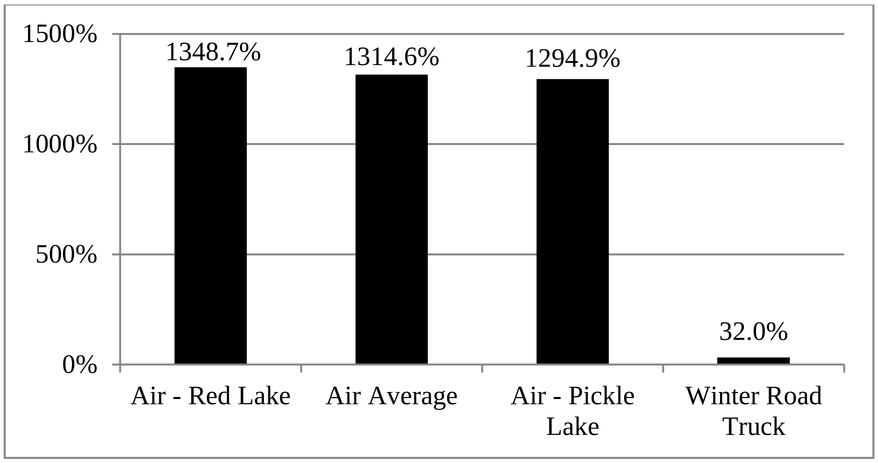

Figure 24 – NWON transportation cost per MTK for each mode relative to average highway trucking rates.

Air and truck rates in the NWON are compared to Manitoba highway trucking rates in figure 24. All freight rates are weighted by MTK. No highway trucking rates are available for the shipments from Winnipeg to Red Lake or Pickle Lake so the Manitoba rate is used instead. It is assumed that this rate would apply because the NWC is likely able to negotiate similar rates across carriers and because of the high level of competition in the trucking industry. As shown in figure 24, air rates are approximately 13 to 13.5 times higher than highway trucking rates, while winter road trucking rates are approximately 32% higher. Between the high cost of air freight and the high level of dependence on air transport for re-supply, there is a significant opportunity for reducing total transportation costs through innovation in air transport modes.

6.3 The Cargo Airship Alternatives

The two cargo airship alternatives tested in the NWON are conceptually identical to the two ESLW cargo airship alternatives. The first alternative involves replacing traditional air freight flows with cargo airship flows while keeping winter road trucking flows fixed. This alternative changes only the cost vectors associated with using traditional aircraft with those associated with using cargo airships. This again reflects the assumption that users will learn over time how the unique operational capabilities of cargo airships may alter the NWON re-supply network but initially the new mode of transport is used in a fashion that is most similar to current practices.

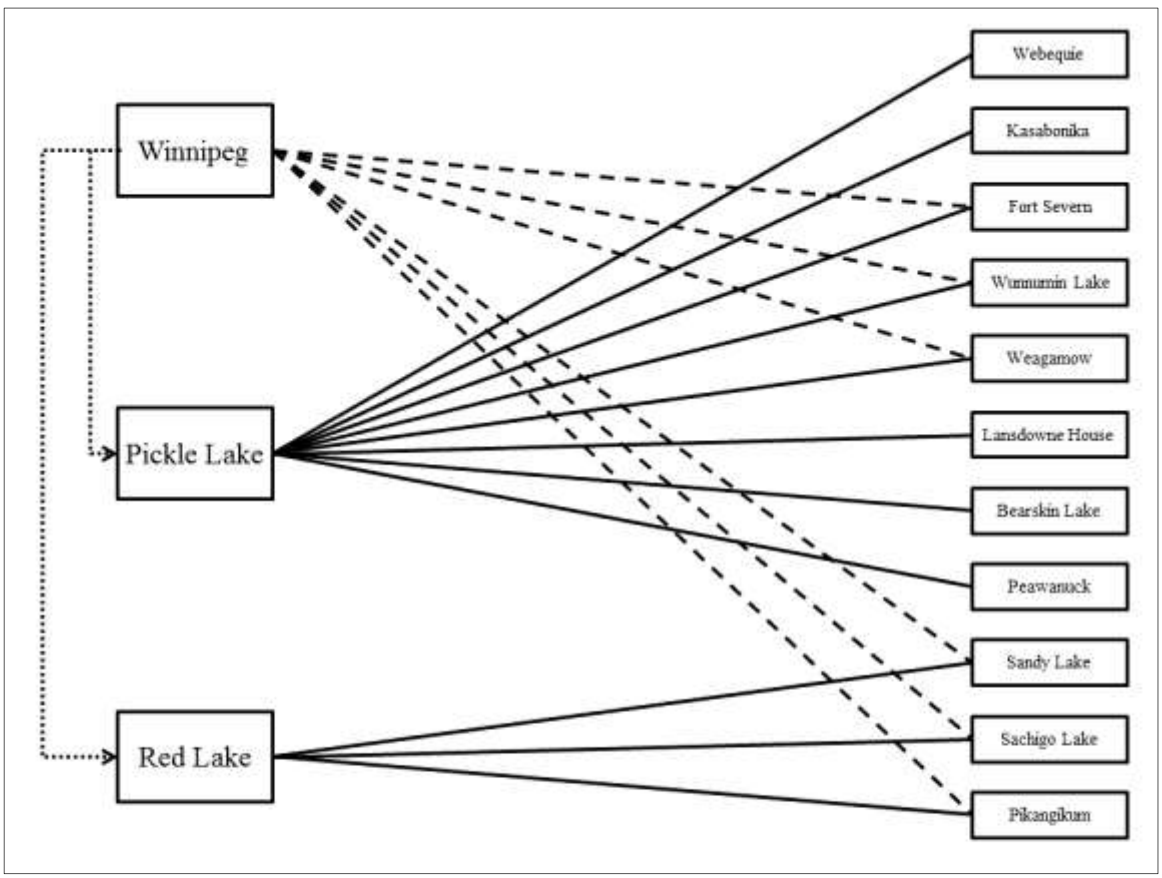

Figure 25 - Diagram of freight flows for NWON cargo airship alternative 1. The dotted lines represent the highway trucking flows, the long-dashed lines represent winter road trucking flows, and the solid lines represent cargo airship flows.

The freight flows for alternative 1 are illustrated in figure 25. The long-dashed lines from Winnipeg to each of the NWON communities depict the winter road trucking flows and the dotted lines from Winnipeg to Pickle Lake and Red Lake depict the highway trucking flows. These remain unchanged from the baseline scenario. The solid lines from Pickle Lake and Red Lake to the 11 communities depict the cargo airship freight flows. The net change on total transportation costs relative to the baseline scenario result from these flows.

Table 25 – Cargo airship freight flows for NWON alternative 1.

Origin	Destination	t	km	MTK
Pickle Lake	Webequie	582.2	257	149.6
	Kasabonika	400.5	255	102.1
	Severn	155.5	536	83.3
	Wunnumin Lake	397.3	173	68.7
	Weagamow	232.4	183	42.5
	Lansdowne House	210.3	178	37.4
	Bearskin Lake	126.6	286	36.2
	Peawanuck	59.5	506	30.1
	Total – Pickle Lake	2164.3		549.9
Red Lake	Sandy Lake	881.3	224	197.4
	Sachigo Lake	187.1	332	62.1
	Pikangikum	686.6	84.7	58.2
	Total Red Lake	1755.0		317.7
	Total	3919.3		867.6

t: Annual freight demand in metric tonnes.
km: Distance from origin to destination in kilometres.
MTK: Metric-tonne kilometres (1,000's).

The cargo airship freight flows are described in table 25. In total, the NWC's re-supply demand would require approximately 867.6 thousand MTK. More than half of total cargo airship MTK derives from freight flows that originate Pickle Lake (63.4%)

while the balance derives from flows from Red Lake (36.4%). Because this alternative assumes no change to the winter road trucking freight flows, these are not described again. Total annual transportation costs for alternative 1 are compared to the baseline annual costs using the existing modes of transportation in the NWON region as described earlier.

The cost analysis for this alternative compares the total annual transportation costs of the cargo airship system to the same for the existing system. The difference in cost between the two systems is represented in percentage form to show the system-level impact of the cargo airship. The cost comparison calculation is expressed mathematically in equation 15. Note that pilot costs are doubled for the trips from Pickle Lake to Fort Severn and Peawanuck because they require more than eight occupied hours.

Cost difference for cargo airship alternative 1:

$$D = \frac{[\mathrm{HT} + \mathrm{WR} + \mathrm{CA}] - [\mathrm{HT} + \mathrm{WR} + \mathrm{AC}]}{[\mathrm{HT} + \mathrm{WR} + \mathrm{AC}]}$$

HT: Annual Highway Trucking Costs
WR: Annual Winter Road Trucking Costs
CA: Annual Cargo Airship Costs
AC: Annual Conventional Aircraft Costs

Equation 15 - Cost differential equation for NWON cargo airship alternative 1.

The second alternative assumes winter roads are no longer viable. In this event all winter road trucking freight flows are shifted to air freight flows using either the cargo airship or conventional aircraft. The total annual freight transportation costs of shipping all freight into the NWON region by conventional aircraft and by cargo airship are compared with one another and with the baseline total annual transportation costs. This provides a comparison between conventional aircraft and cargo airships and also provides insight into how the loss of the winter road network may affect the region.

The freight flows for alternative 2 are illustrated in figure 26. The dotted lines again depict the highway trucking freight flows from Winnipeg to the trans-shipment points in Pickle Lake and Red Lake. The incremental cost of transporting the quantity of freight to each trans-shipment point that flow over the winter road system is included in total transportation costs. The solid lines from Pickle Lake to Red Lake to the 11 communities in the region depict air freight flows. These flows apply to both conventional aircraft and the cargo airship.

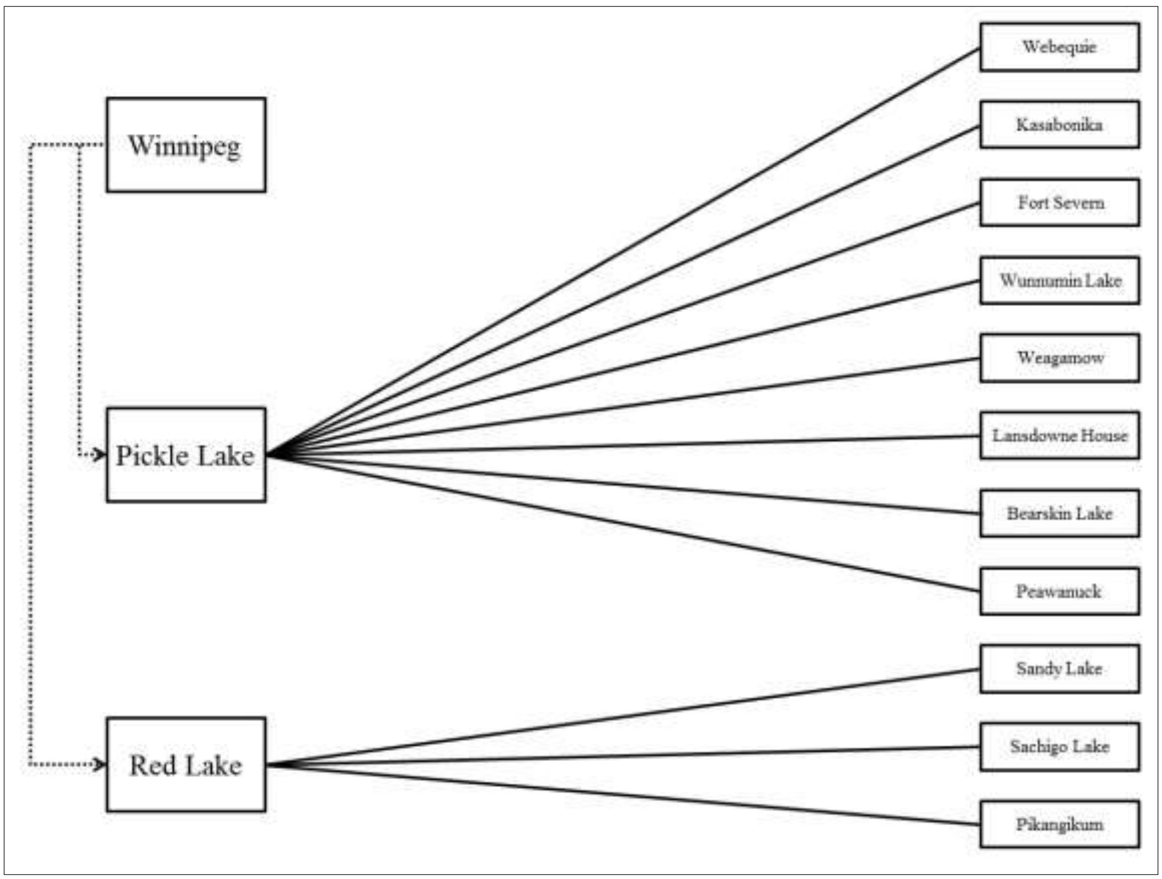

Figure 26 - Diagram of freight flows for NWON cargo airship alternative 2. The dotted lines represent highway trucking flows and the solid lines represent conventional aircraft and cargo airship flows.

Table 26 describes the air freight flows that result from shifting all winter road truck traffic to air. Total freight quantities for each store in table 26 are identical to the total store-level demand quantities described earlier. The split is nearly 50/50 between freight flows that originate from Pickle Lake and Red Lake in terms of freight quantities, however approximately 60% of total air MTK originate from Pickle Lake. The freight flows between O-D pairs described in table 26 also apply to traditional aircraft.

Table 26 - Air freight flows for NWON alternative 2.

Origin	Destination	t	km	MTK
Pickle Lake	Webequie	582.2	257	149.6
	Kasabonika	400.5	255	102.1
	Severn	218.8	536	117.3
	Wunnumin Lake	430.2	173	74.4
	Weagamow	292.9	183	53.6
	Lansdowne House	210.3	178	37.4
	Bearskin Lake	126.6	286	36.2
	Peawanuck	59.5	506	30.1
	Total – Pickle Lake	2321.0		600.7
Red Lake	Sandy Lake	1085.3	224	243.1
	Sachigo Lake	226.1	332	75.1
	Pikangikum	877.7	84.7	74.3
	Total Red Lake	2189.1		392.5
	Total	4510.1		993.2

t: Annual freight demand in metric tonnes.
km: Distance from origin to destination in kilometres.
MTK: Metric-tonne kilometres (1,000's).

The highway freight flows for the second alternative are described in table 27 on the following page. The average highway trucking rates for Manitoba are applied to these flows because no highway trucking costs are available for the NWON are available in the dataset provided by the NWC. In total, 590.8t of freight is shipped from Winnipeg to both Pickle Lake and Red Lake by highway trucking. The majority of this freight is shipped to Red Lake. Total the total freight quantity shipped to Red Lake is nearly three times greater than the quantity shipped to Pickle Lake. These freight flows again apply for both cargo airships and traditional aircraft.

Table 27 – NWON alternative 2 highway trucking flows from Winnipeg to Pickle Lake and Red Lake.

Origin	Destination	Quantity - t	Distance - km	MTK
Winnipeg	Pickle Lake	156.7	709	111.1
	Red Lake	434.1	483	209.7
	Total	590.8		320.8

Three cost comparisons are conducted for this alternative, and the comparisons are identical to those for ESLW alternative 2. The equations for these comparisons are expressed in equations 16, 17, and 18.

Cost difference between cargo airship system and baseline system:

$$D = \frac{[\mathrm{HT} + \mathrm{CA}] - [\mathrm{HT} + \mathrm{WR} + \mathrm{AC}]}{[\mathrm{HT} + \mathrm{WR} + \mathrm{AC}]}$$

HT: Annual Highway Trucking Costs
CA: Annual Cargo Airship Costs
WR: Annual Winter Road Trucking Costs
AC: Annual Conventional Aircraft Costs

Equation 16 - Cost difference between cargo airship system and baseline system in NWON alternative 2.

Cost difference between conventional aircraft system and baseline system:

$$D = \frac{[\mathrm{HT} + \mathrm{AC}] - [\mathrm{HT} + \mathrm{WR} + \mathrm{AC}]}{[\mathrm{HT} + \mathrm{WR} + \mathrm{AC}]}$$

HT: Annual Highway Trucking Costs
AC: Annual Conventional Aircraft Costs
WR: Annual Winter Road Trucking Costs

Equation 17 - Cost difference between conventional aircraft system and baseline system in NWON alternative 2.

Cost difference between cargo airship system and conventional aircraft system:

$$D = \frac{[\text{HT + CA}] - [\text{HT + AC}]}{[\text{HT + AC}]}$$

HT: Annual Highway Trucking Costs

CA: Annual Cargo Airship Costs

AC: Annual Conventional Aircraft Costs

Equation 18 - Cost difference between conventional aircraft system and baseline system in NWON alternative 2.

6.4 NWON Results

NWON alternative 1 assumes all air freight flows are transported by cargo airship while winter road trucking flows remain unchanged. Cargo airship operating requirements for this alternative are summarized in table 28 on the following page. Serving the NWON region in this alternative requires a total of 328.9 and 430.4 block hours and occupied hours respectively. These accrue over 78.1 cargo airship trips annually. The split in annual trips between the communities served by Red Lake and Pickle Lake is nearly even. However, nearly two-thirds of block hours and occupied hours are accounted for by communities served from Pickle Lake. At the community level, Sandy Lake accounts for the greatest number of cargo airship block and occupied hours (75.7 and 98.6) while Peawanuck accounts for the least (10.6 and 12.1). Total cargo airship MTK is almost 0.87 million.

Table 28 - Summary of cargo airship activity for NWON alternative 1.

Origin	Destination	t	km	MTK	Trips	BH	OH
Pickle Lake	Webequie	582.2	257	149.6	11.6	55.7	70.8
	Kasabonika	400.5	255	102.1	8.0	37.6	48.0
	Severn	155.5	536	83.3	3.1	28.5	32.6
	Wunnumin Lake	397.3	173	68.7	7.9	26.9	37.1
	Weagamow	232.4	183	42.5	4.6	16.6	22.5
	Lansdowne House	210.3	178	37.4	4.2	14.7	20.2
	Bearskin Lake	126.6	286	36.2	2.5	13.0	16.3
	Peawanuck	59.5	506	30.1	1.2	10.6	12.1
	Total Pickle Lake	2164.3		549.9	43.1	203.6	259.6
Red Lake	Sandy Lake	881.3	224	197.4	17.6	75.7	98.6
	Sachigo Lake	187.1	332	62.1	3.7	22.2	27.0
	Pikangikum	686.6	84.7	58.2	13.7	27.4	45.2
	Total Red Lake	1755.0		317.7	35	125.3	170.8
	Total	3919.3		867.6	78.1	328.9	430.4

t: Annual freight quantity in t.
km: Trip distance between origin and destination pair.
Trips: Annual cargo airship trips.
MTK: Annual cargo airship MTK.
BH: Annual cargo airship block hours.
OH: Annual cargo airship occupied hours.

The cost impact of the cargo airship is summarized by community in table 29. Also, the results are illustrated on the conceptual map of the NWON featured in figure 27 on page 94. Cost savings for all communities range between approximately 33% and up to almost 50%. The weighted average cost savings for all communities is 38.3%. In terms of percentages, Peawanuck experiences the greatest cost savings (49.5%) while Weagamow experiences the least (32.9%). Sandy Lake experiences the greatest cost savings in dollar terms while Bearskin Lake experiences the least. Cost savings are likely higher in the NWON than in the ESLW because winter road trucking plays a relatively smaller role in the former region than in the latter.

Table 29 - Cost comparison results for NWON alternative 1.

Trans-ship	Community	HWY t	CA t	WR t	*D*
Pickle Lake	Webequie	582.2	582.2	0.0	-38.6%
	Kasabonika	400.5	400.5	0.0	-40.8%
	Severn	155.5	155.5	63.3	-37.1%
	Wunnumin Lake	397.3	397.3	32.9	-36.3%
	Weagamow	232.4	232.4	60.4	-32.9%
	Lansdowne House	210.3	210.3	0.0	-34.5%
	Bearskin Lake	126.6	126.6	0.0	-38.9%
	Peawanuck	59.5	59.5	0.0	-49.5%
Red Lake	Sandy Lake	881.3	881.3	204.0	-37.4%
	Sachigo Lake	187.1	187.1	39.1	-38.2%
	Pikangikum	686.6	686.6	191.1	-40.6%
	Total	3,919.3	3,919.3	590.8	-38.3%

Trans-ship: Trans-shipment point between highway trucking and the cargo airship.
HWY t: Highway trucking freight quantity (t).
CA t: Cargo airship freight quantity (t).
WR t: Winter road freight quantity (t).
D: Cost difference between NWON cargo airship alternative 1 and the baseline NWON system.

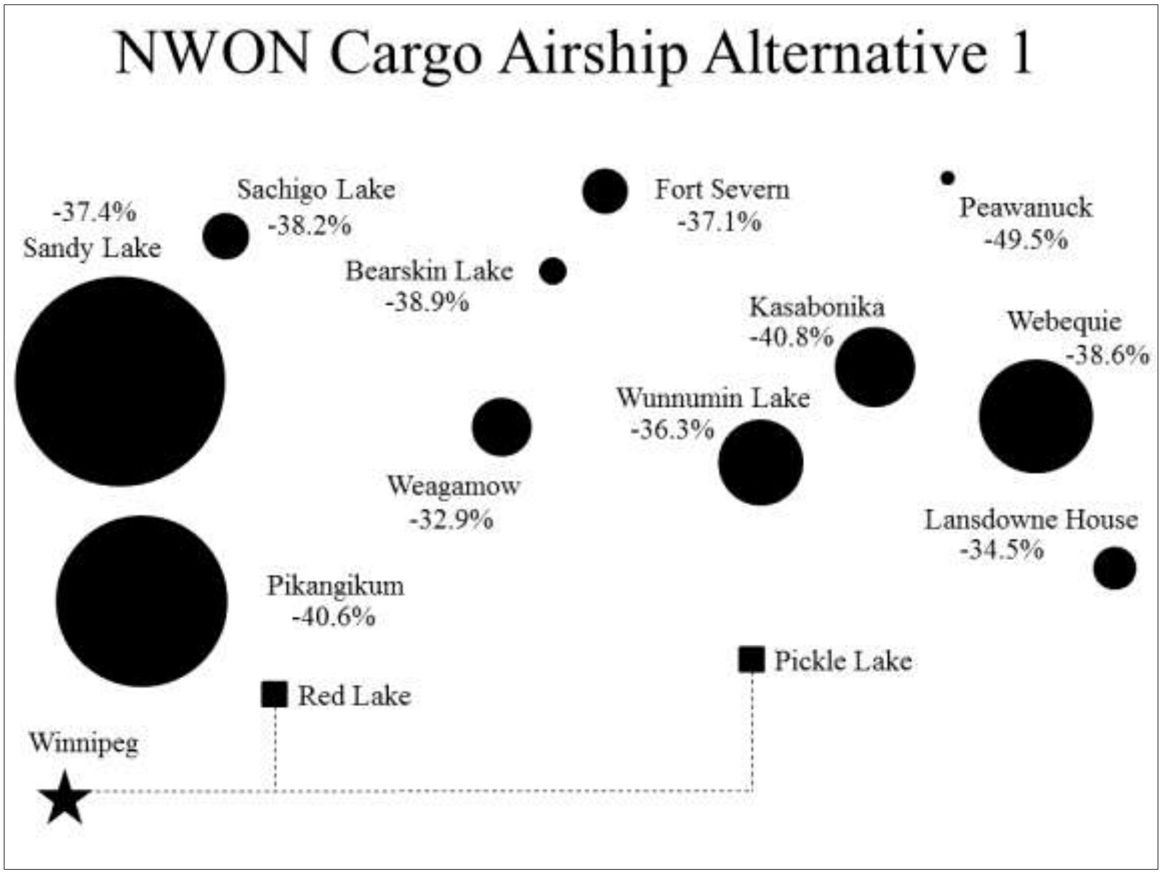

Figure 27 - Map of results from NWON cargo airship alternative 1.The percentages indicate the proportional cost differential between the baseline NWON freight transportation system costs and the cargo airship alternative 1 in which the cargo airship replaces conventional aircraft and winter road trucking remains fixed. The percentages shown in this map correspond to *D* shown in table 29.

Alternative 2 assumes all freight is moved by air, whether using a cargo airship or using conventional aircraft. The cargo airship operational requirements are summarized in table 30 on the following page. Total annual cargo airship utilization increases slightly to 0.99 million, while block hours and occupied hours increase to 378.4 and 497.1 respectively. There is a nearly 60/40 split in terms of MTK between the communities served by Pickle Lake and Red Lake. This is reflected in the number of block hours and occupied hours accounted for by the communities served by each trans-shipment point. Sandy Lake accounts for the greatest number of operational hours (93.3 BH and 121.5 OH) while Peawanuck still accounts for the least (10.6 BH and 12.1 OH). The two communities also account for the greatest and least number of cargo airship trips made annually.

Table 30 - Summary of cargo airship activity for NWON alternative 2.

Origin	Destination	t	km	MTK	Trips	BH	OH
Pickle Lake	Webequie	582.2	257	149.6	11.6	55.7	70.8
	Kasabonika	400.5	255	102.1	8.0	37.6	48.0
	Severn	218.8	536	117.3	4.4	40.5	46.2
	Wunnumin Lake	430.2	173	74.4	8.6	29.2	40.4
	Weagamow	292.9	183	53.6	5.9	21.2	28.9
	Lansdowne House	210.3	178	37.4	4.2	14.7	20.2
	Bearskin Lake	126.6	286	36.2	2.5	13.0	16.3
	Peawanuck	59.5	506	30.1	1.2	10.6	12.1
	Total Pickle Lake	2,321.0		600.7	46.4	222.5	282.9
Red Lake	Sandy Lake	1,085.3	224	243.1	21.7	93.3	121.5
	Sachigo Lake	226.1	332	75.1	4.5	27.0	32.9
	Pikangikum	877.7	84.7	74.3	17.6	35.6	59.8
	Total Red Lake	2,189.1		392.5	43.8	155.9	214.2
	Total	4,510.1		993.2	90.2	378.4	497.1

t: Annual freight quantity in t.
km: Trip distance between origin and destination pair.
Trips: Annual cargo airship trips.
MTK: Annual cargo airship MTK.
BH: Annual cargo airship block hours.
OH: Annual cargo airship occupied hours.

The cost impact of the cargo airship is summarized by community in table 31 on the following page. The results from the comparison between the cargo airship system and the baseline NWON system are illustrated in figure 28 on page 97. D_1 is the cost differential between the cargo airship system and the baseline system. Cost savings are slightly lower than in the first alternative however the shift of freight from winter road trucking to the cargo airship nonetheless allows for cost savings of between 22% and nearly 50%. Note that cost savings for some communities did not change because they do not use winter road trucking in the baseline system. D_2 shows the cargo airship system is between 34% and 50% less costly than the conventional aircraft-only system. This is also reflected in D_3 which shows that the communities that use winter road trucking would experience cost increases of 6% and 21% if winter road trucking were no longer available and conventional aircraft were the only mode available to serve the region.

Table 31 - Cost comparison results for NWON alternative 2.

Trans-ship	Community	HWY t	CA t	D_1	D_2	D_3
Pickle Lake	Webequie	582.2	582.2	-38.6%	-38.6%	0.0%
	Kasabonika	400.5	400.5	-40.8%	-40.8%	0.0%
	Severn	218.8	218.8	-31.2%	-42.9%	20.5%
	Wunnumin Lake	430.2	430.2	-31.8%	-36.4%	7.3%
	Weagamow	292.9	292.9	-22.1%	-34.3%	18.5%
	Lansdowne House	210.3	210.3	-34.5%	-34.5%	0.0%
	Bearskin Lake	126.6	126.6	-38.9%	-38.9%	0.0%
	Peawanuck	59.5	59.5	-49.5%	-49.5%	0.0%
Red Lake	Sandy Lake	1,085.3	1,085.3	-32.4%	-36.6%	6.6%
	Sachigo Lake	226.1	226.1	-32.0%	-37.1%	8.0%
	Pikangikum	877.7	877.7	-28.9%	-35.6%	10.4%
	Total Impact	4,510.1	4,510.1	-34.0%	-38.0%	6.5%

Trans-ship: Trans-shipment point between highway trucking and the cargo airship.
HWY t: Highway trucking freight quantity (t).
CA t: Cargo airship freight quantity (t).
D_1: Cost difference between NWON 2 and the baseline NWON system.
D_2: Cost difference between NWON 2 and the conventional aircraft system.
D_3: Cost difference between the conventional aircraft system and the baseline NWON system.

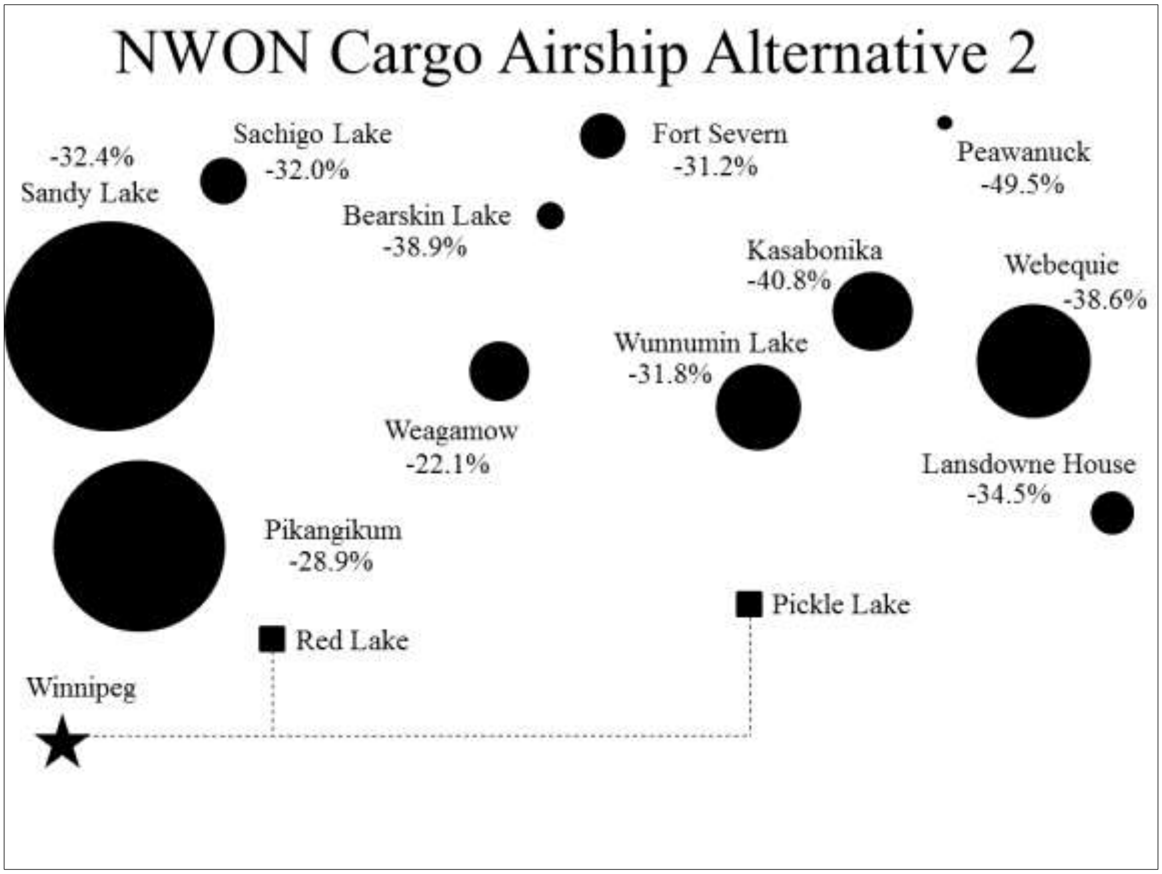

Figure 28 - Map of results from NWON cargo airship alternative 2.The percentages indicate the proportional cost differential between the baseline NWON freight transportation system costs and cargo airship alternative 2 in which the cargo airship carries all freight to each community from the two trans-shipment points. The percentages shown in this map correspond to D_1 shown in table 31.

The within-case comparison between NWON alternatives 1 and 2 is summarized in table 32 on the following page. There is no difference in cost between the two alternatives for the six communities that do not use winter road trucking. Transportation costs increase for the communities that do use winter road trucking when that mode of transportation is no longer used. Pikangikum and Weagamow experience a cost increase of approximately 11% while Fort Severn, Wunnumin Lake, Sandy Lake, and Sachigo Lake experience cost increases of approximately 5%. In total, the airship-only alternative is 4.3% more costly.

Table 32 - Cost savings (vs. baseline) comparison between NWON alternative 1 and NWON alternative 2.

Trans-ship	Community	*D* NWON 1	*D* NWON 2	Difference
Pickle Lake	Webequie	-38.6%	-38.6%	0.0%
	Kasabonika	-40.8%	-40.8%	0.0%
	Fort Severn	-37.1%	-31.2%	5.9%
	Wunnumin Lake	-36.3%	-31.8%	4.5%
	Weagamow Lake	-32.9%	-22.1%	10.8%
	Lansdowne House	-34.5%	-34.5%	0.0%
	Bearskin Lake	-38.9%	-38.9%	0.0%
	Peawanuck	-49.5%	-49.5%	0.0%
Red Lake	Sandy Lake	-37.4%	-32.4%	5.0%
	Sachigo Lake	-38.2%	-32.0%	6.1%
	Pikangikum	-40.6%	-28.9%	11.7%
	Total	-38.3%	-34.0%	4.3%

Chapter 7: The Central Nunavut (CENU) Case

7.1 Case Introduction

Figure 29 - Map of the CENU region and the approximate geographic location of its NWC communities. *Modified from*: Canada [computer file]. (no date). St. Catherines, Ontario: Brock University Map Library. Available: Brock University Library Controlled Access http://www.brocku.ca/maplibrary/maps/outline/North_America/TNORTH.pdf. Brock University provides this and other maps for free use by the public.

Of the three regions included in this study, the CENU region is the most remote. Arviat is 1,263 KM away by air from the NWC's distribution centre in Winnipeg and it is the most proximate of the CENU communities. The approximate geographic location of the CENU communities is illustrated in the map of the region in figure 29.

The physical geography of the CENU region is classified as arctic tundra (Government of the Northwest Territories, 2005). Although it has been acknowledged that a greater level of understanding of the Arctic's climatic processes is necessary, climate change is generally expected to impact the Arctic more severely than locations near the equator (Melles et al, 2012). A warming climate has and is expected to further negatively impact local ecosystems, infrastructure, and the people of the region (Sullivan & Nasmith, 2010). From a social perspective, economic prospects for many residents of Nunavut are low in comparison with the average Canadian (Tester, 2009). The high cost of operating in a region like CENU translates into high prices at the retail level, especially in relation to lower than average incomes. Indeed, high food prices have given rise to local citizen activism (Strapagiel, 2012).

Within this challenging context, the NWC operates retail outlets in Arviat, Rankin Inlet, Baker Lake, Coral Harbour, Chesterfield Inlet, and Repulse Bay providing food and general merchandise. The total surface area of the region, calculated in the same manner as the previous two cases, is 147,553km^2. The populations of the six communities are presented in table 33. In addition to being the most remote of the three regions analyzed, this region is also the least densely populated.

Table 33 - CENU community population data. Source: Statistics Canada (2006).

Community	Population	Community	Population
Rankin Inlet	2,358	Coral Harbour	769
Arviat	2,060	Repulse Bay	748
Baker Lake	1,728	Chesterfield Inlet	332
		Total	7,995

The CENU region is the only one of the three that receives freight by maritime transport. Because this mode is unique to the region, it is relevant to discuss how climate change is affecting maritime accessibility. The warming of the Arctic has already increased maritime accessibility and the length of the maritime shipping season to destinations in the northern latitudes, and this trend is expected to continue into the future (Bert, 2012; Derksen et al, 2012; Sullivan & Nasmith, 2010). A longer maritime shipping season could imply that an increasing quantity of freight shipped to the region will shift from air to maritime modes in the future. However, much of the freight shipped by the NWC into the region by sea is food, and much of the food is likely to be perishable. Consequently, the quantity of freight shipped by air is likely to be stable even if maritime accessibility were to increase significantly.

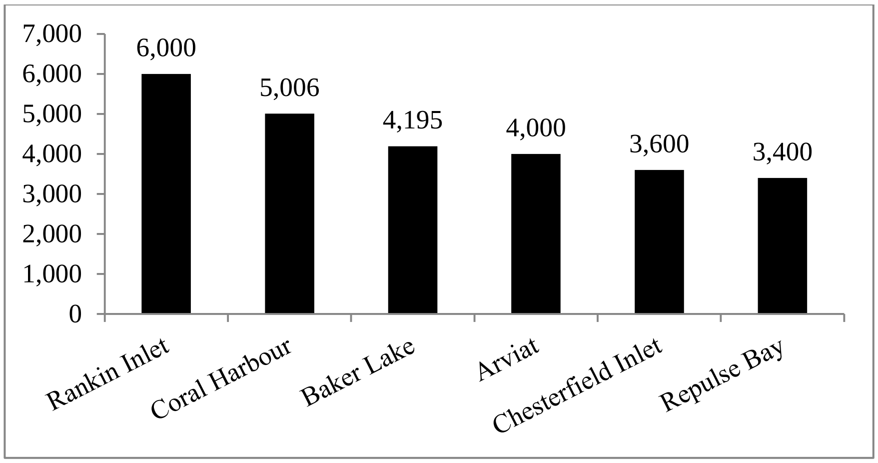

Figure 30 – CENU community airstrip lengths in feet. Source: Nav Canada (2013).

The region relies heavily on air transport for re-supply at present. Community airstrip lengths are presented in figure 30. In comparison with the other two regions, the airstrips in the CENU region are relatively long. This allows service to the communities with aircraft like the Boeing 737-200 combi, a jet with a maximum possible payload capacity of 14 T (First Air, 2013). The communities with shorter airstrips can be served by mid-size regional aircraft like the ATR-42 and the ATR-72, each capable of carrying a maximum payload of 4.5 and 7 metric tonnes respectively. The use of larger aircraft in the CENU region in comparison with the other two regions presents a unique competitive environment in the air transport market; although the distances are longer, the aircraft used in the region are larger and more efficient.

7.2 The North West Company's CENU Operations

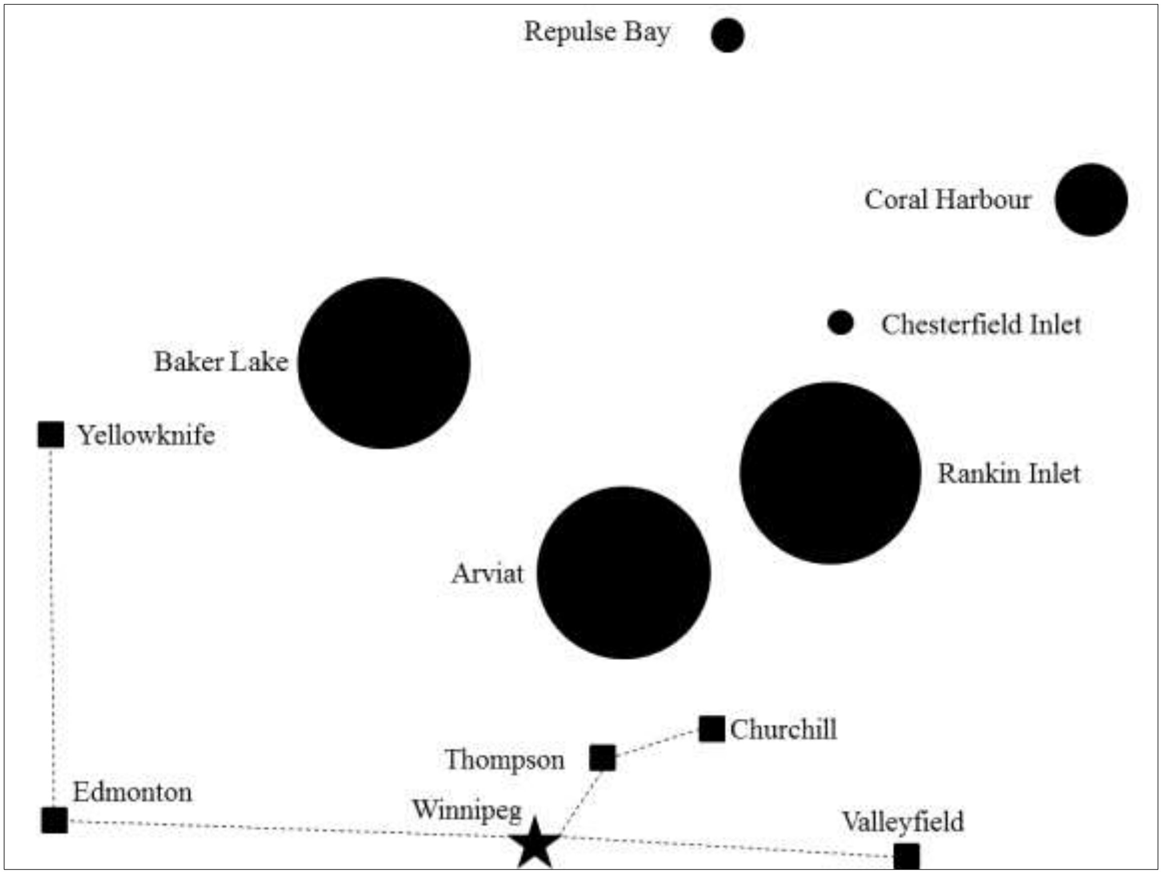

Figure 31 - Conceptual map of the NWC's CENU trading area. Store markers are scaled by total freight quantity (t).

A conceptual map of the region is illustrated in figure 31. The markers for each of the six stores have been scaled in diameter to illustrate each store's total freight demand relative to Chesterfield Inlet. The dashed lines represent the surface transportation network. Note that the link between Thompson and Churchill is a rail line. The total trading area exclusive of the freight origins is 147,553km^2 with a perimeter of 1,851km. For reference, the CENU region is almost as large as the other two regions combined, and it is more than twice the surface area of Ireland (Central Intelligence Agency, 2013).

Table 34 - Freight quantity data by type (t) and mode for all community stores.

Community	Maritime–Food	Maritime-GM	Air-Food	Air-GM	Total
Rankin Inlet	345.5	4.1	452.5	117.3	919.4
Arviat	0.0	14.2	721.4	142.8	878.4
Baker Lake	311.7	44.7	436.4	79.6	872.4
Coral Harbour	213.8	31.6	86.5	26.6	358.5
Repulse Bay	98.9	7.1	36.1	15.0	157.1
Chesterfield Inlet	49.3	3.7	54.4	9.8	117.2
Total	1,019.2	105.4	1,787.3	391.1	3,303.0

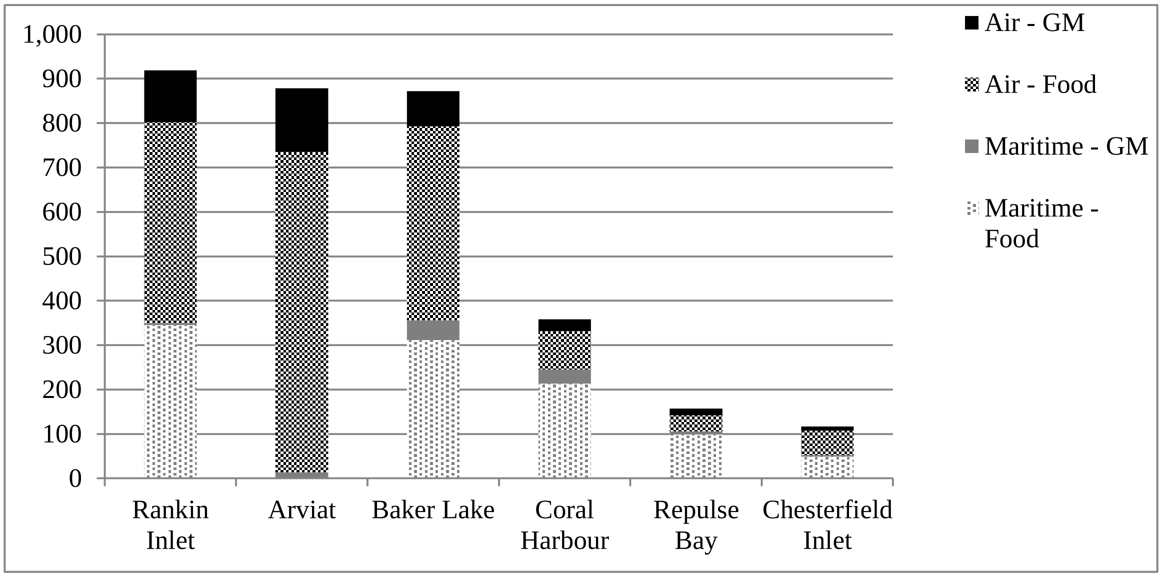

Figure 32- Freight quantity data by type and mode (t) for all CENU communities.

Store-level freight receipt quantities are summarized in table 34 in terms of freight types and modes of transport. The modes of transport shown in the table are those used for delivery to the stores in each community. These data are also illustrated in figure 32 above. Across the entire region, a total of 3,303.0t of freight is shipped to six stores. The store with the highest level of total demand is Rankin Inlet, with 919.4t, while the store with the lowest demand is Chesterfield Inlet, with 117.2t. Rankin Inlet, Arviat, and Baker Lake together receive 80.8% of the total freight shipped to the region, 80.8% of the food, and 81.1% of the GM. Conversely, Repulse Bay and Chesterfield Inlet combine for 8.3% of total freight receipts in the region.

In terms of modal usage, air dominates over maritime shipping for re-supply. Of the total 3,303.0t of freight transported into the region, 2,178.4t is transported by air and 1,124.6t is transported by sea. This translates into a modal split of approximately 66% and 34% for air and maritime respectively. At the store level, Arviat receives the greatest quantity of freight by air (864.2t), while Repulse Bay receives the least (51.1t). For maritime freight movements, Baker Lake receives the most freight (356.4t) while Arviat receives the least (14.2t).

Of the total freight shipped into the region, 2,806.5t is food and 496.5t is GM. Average food and GM freight receipts at the store-level are 467.8t and 82.8t respectively. Rankin Inlet demands the greatest amount of food (798 T) while Chesterfield Inlet demands the least (103.7t), and Rankin Inlet has the greatest demand for GM (157.0t) while Chesterfield Inlet has the least (13.5t). Across all stores, the average split between food and GM is 85.5% and 15.5% respectively.

The freight origin data are presented in table 35. Although the majority of the freight is shipped by air from Churchill, the most proximate of the trans-shipment points to the region, a significant amount of freight is shipped directly from Winnipeg. The former would suggest that the NWC reduces air transport costs by reducing air transport distances but the latter suggests that the company achieves cost reductions by shipping freight on larger aircraft with greater range and payload capacity that operate out of Winnipeg. This is not an option available in the other two regions, and it reveals how community airport infrastructure can act to alter freight routing decisions. Note that all maritime freight flows originate in Valleyfield, Quebec.

Table 35 – Freight flows from each origin, exclusive of truck and rail shipments to trans-shipment points, in metric tonnes.

Mode	Origin	Food (t)	GM (t)	Total
Air	Churchill	1,241.6	261.9	1,503.5
	Winnipeg	422.0	117.1	539.1
	Thompson	93.2	10.6	103.8
	Yellowknife	30.5	1.4	31.9
Maritime	Valleyfield	1,019.2	105.4	1,124.60

Air MTK is presented in table 36 on the following page. Note that all MTK figures are presented in 1,000's and are rounded to the nearest 100 MTK. Distances between O-D pairs are determined using the same methodology as the other cases. Also note that MTK figures for maritime freight flows are not included because vessel route data are unavailable. The effect of long distances in the CENU region is evident in the total MTK figures. For example, the quantity of freight shipped by air from Churchill is approximately three times greater than that from Winnipeg however MTK for each origin is nearly equal.

Air MTK attributable to each store is presented in table 37. Each of the stores is re-supplied from different points of origin Note again that maritime MTK is not included because distances are unavailable. Although Baker Lake received the greatest quantity of freight, it places second in terms of MTK. Rankin Inlet, which receives the second highest quantity of freight, accounts for nearly three times as much MTK as Baker Lake. Total air MTK for each store is shown in table 37, with the stores ranked in order from highest total MTK to lowest. Rankin Inlet demands more than twice as much air transport as Baker Lake, and more than three times as much as Arviat. These data again show a trend that freight transportation demand is concentrated within the region.

Table 36 – Air freight MTK by point of origin by store from highest MTK to lowest (In 1,000's).

Origin	Destination	Quantity (t)	Distance (km)	MTK
Churchill	Baker Lake	491.2	629	309.0
	Arviat	796.4	263	209.5
	Coral Harbour	106.5	832	88.6
	Repulse Bay	48.1	955	45.9
	Chesterfield Inlet	61.3	544	33.3
			Total - Churchill	686.3
Thompson	Arviat	66.8	630	42.1
	Baker Lake	24.8	952	23.6
	Coral Harbour	6.6	1,231	8.1
	Repulse Bay	2.8	1,344	3.8
	Chesterfield Inlet	2.8	931	2.6
			Total - Thompson	80.2
Winnipeg	Rankin Inlet	537.9	1,472	791.8
	Arviat	1.0	1,263	1.3
	Repulse Bay	0.2	1,955	0.4
	Chesterfield Inlet	0.1	1,549	0.2
			Total - Winnipeg	793.7
Yellowknife	Rankin Inlet	31.9	1,140	36.3
			Total - Yellowknife	36.3
			Total	1,596.5

Table 37 – Air MTK for each CENU store, in order from highest total MTK to lowest.

Store	Churchill	Thompson	Winnipeg	Yellowknife	Total MTK
Rankin Inlet	0	0	791.8	36.3	828.1
Baker Lake	309	23.6	0	0	332.6
Arviat	209.5	42.1	1.3	0	252.9
Coral Harbour	88.6	8.1	0	0	96.7
Repulse Bay	45.9	3.8	0.4	0	50.1
Chesterfield Inlet	33.3	2.6	0.2	0	36.1
				Total	1,596.1

Staging freight at the trans-shipment points in the network requires the use of rail and highway trucking. These modes are referred to in the rest of these analyses as surface intermodal (SIM). There are five paths through the re-supply network and each varies in terms of modal split. The SIM flows are described in table 38. Because these paths vary in modal split, unlike in the other cases, they are all referred to collectively as SIM paths.

Table 38 – Surface Intermodal (SIM) freight paths through the CENU re-supply network, ranked by t.

Flow	Origin	Destination	Surface Mode	Quantity (t)
WPG-TL-VFD	Winnipeg	Montreal	Rail	
	Montreal	Valleyfield	Highway Truck	1,124.6
WPG-THO-CHL	Winnipeg	Thompson	Highway Truck	
	Thompson	Churchill	Rail	1503.5
WPG-THO	Winnipeg	Thompson	Highway Truck	103.8
WPG-EDM-YKF	Winnipeg	Edmonton	Highway Truck	
	Edmonton	Yellowknife	Highway Truck	31.9

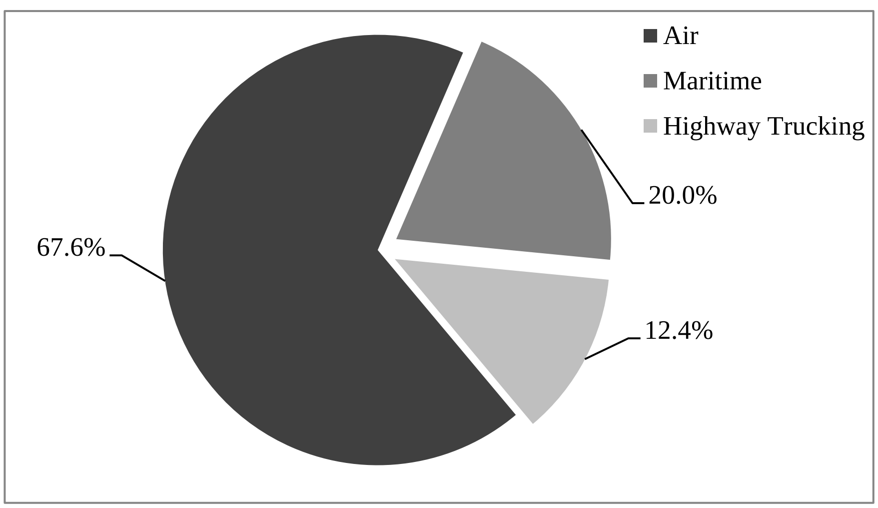

Figure 33 – CENU proportion of total annual transportation costs by mode.

Modal cost proportions are illustrated in figure 33. Note that in this case the highway trucking costs are included because they change significantly in the alternatives presented later. As will be discussed subsequently, the cargo airship alternatives drastically alter the structure of the freight transportation network in this region in comparison with the previous two regions.

The majority of total annual transportation costs in the region accrue from air transport. Air transport costs alone account for approximately two-thirds of total transportation costs and this rises to 87.6% when the trucking costs are added to them as a full landed cost. Conversely, maritime freight costs account for 12.4% of total annual transportation costs even though approximately one-third of the total freight quantity shipped into the region is carried by this mode.

Analysis of the air freight rates relative to average highway trucking rates in Manitoba reveals the relationship between point of origin and the characteristics of the aircraft used to service the CENU communities. The relative magnitudes of air freight rates from each point of origin relative to average highway trucking rates from the ESLW case region are illustrated in figure 34 on the following page. The highest weighted air freight rates are found in the origins nearest the CENU region while the lowest are found in the origins the furthest away. The rates in the former are between nine and ten times higher than highway trucking rates, while in the latter rates are between three and four times higher. Although this could be partially due to the freight rate taper effect[11] (McCann, 2001), it is likely because larger classes of aircraft serve the region in comparison with the other regions. Note, however, that although the cost per MTK is relatively lower in the CENU by air than in other regions, the total landed cost in dollars is far higher because of the longer distances.

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[11] The freight rate taper effect (McCann, 2001) is the observed phenomenon of decreasing costs per ton-mile as distance increases. This can happen because fixed trip costs, like the cost of loading and unloading of freight for example, are spread over greater distances.

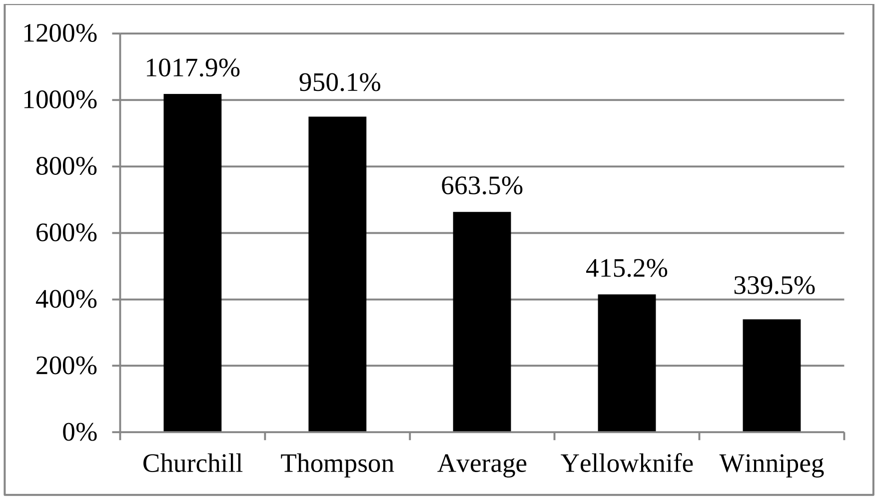

Figure 34 - Relative magnitude of CENU air freight rates by origin to highway trucking rates.

Maritime freight rates, in terms of dollars per MTK, are not present in figure 34 because distance data are unavailable. In addition, the NWC is charged a flat rate per container irrespective of destination. It is, however, possible to compare the landed cost per metric tonne of freight between modes. Indeed, this provides insight into the effect that distance in the CENU region has even on maritime transport, presumably the lowest cost form of transport available to the NWC. The output from this analysis is illustrated in figure 35 below.

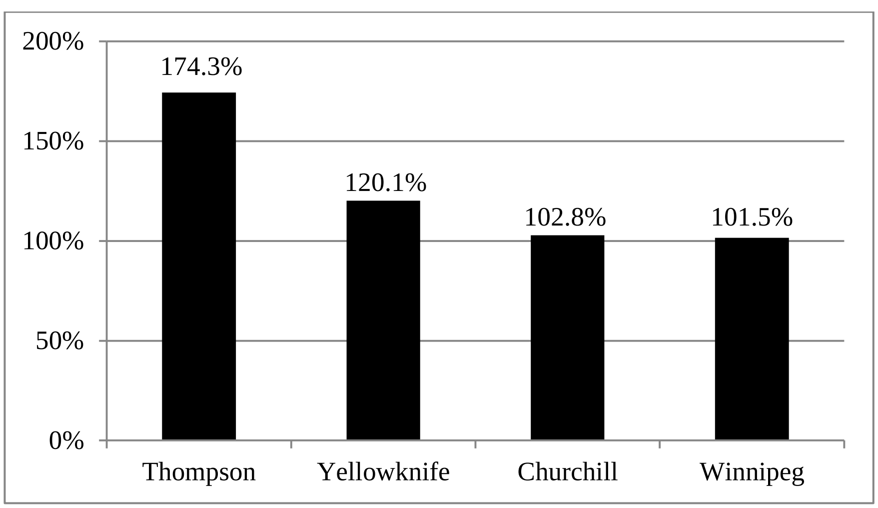

Figure 35 – CENU landed freight costs ($/t) for air relative to landed freight costs ($/t) by maritime.

The landed cost of freight transported by maritime is the lowest between both modes. For this reason this rate serves as the baseline to air freight costs in the comparison in figure 35. The air freight flows include both the SIM and air transport portions of the trip whereas the maritime freight flow is direct from Valleyfield, Quebec to the CENU communities. Although air transport is evidently more costly than maritime transport, the differential between these two modes is not as extreme as might be expected *a priori*. Perhaps the cost of maritime transport on a per tonne-mile basis is significantly lower than air transport however the long distances to the CENU communities function as an equalizer.

7.3 The Cargo Airship Alternatives

The CENU region's unique characteristics demanded the formulation of four cargo airship alternatives. Although this region has the least number of destinations, formulating transportation alternatives is complex due to the long distances between them and their origins. In addition, the availability of maritime freight transportation presents an interesting point of comparison. Thus two parent conditions are included that dictate the formulation of the four cargo airship alternatives. The first parent condition is that the cargo airship is used to replace conventional aircraft for the air freight flows and maritime flows remain fixed. Although this requires some re-engineering of the NWC's freight re-supply network, it nonetheless represents the simplest change from one technology to another.

The second condition assumes that all freight shifts to the cargo airship from both conventional aircraft and maritime transport. This presents an opportunity to compare the cost-competitiveness of the cargo airship with maritime transport, a mode that is unavailable in the other case regions. There may be an opportunity for the cargo airship to compete with maritime freight transport under the conditions observed in the CENU region. Moreover, the additional freight quantity provided by the shift from maritime to the cargo airship would have practical implications. This increased quantity of freight would ensure greater utilization of a cargo airship operating in the CENU region.

Table 39 - Freight quantities delivered by cargo airship for CENU conditions 1 and 2.

Community	Condition 1 (t)	Condition 2 (t)	% Change
Rankin Inlet	569.80	919.40	61.4%
Arviat	864.20	878.40	1.6%
Baker Lake	516.00	872.40	69.1%
Coral Harbour	113.10	358.50	217.0%
Repulse Bay	51.10	157.10	207.4%
Chesterfield Inlet	64.20	117.20	82.6%

The quantities of freight shipped by cargo airship to each store in both conditions are described in table 39. The most dramatic increases occur in Coral Harbour and Repulse Bay where cargo airship freight quantities triple. The quantities of freight delivered by airship to Rankin Inlet, Baker Lake, and Chesterfield Inlet increase by approximately two-thirds or more. Arviat is the only community that experiences minimal change. Aside from the obvious increase in airship utilization, the changes in freight quantities may also affect which community acts as a hub in the second scenarios in both conditions. This is discussed in more detail later in this chapter.

One issue common to all scenarios is pilot duty time limitations imposed by Transport Canada regulations. Existing regulations stipulate that airplane pilot duty time is not to exceed 8 hours under normal circumstances, but this can be extended to up to 14 or 20 hours if a second pilot is available for in-flight relief and proper rest facilities are available onboard the aircraft (Transport Canada, 2013). It is assumed in this analysis that existing air transport regulations, as they pertain to conventional aircraft, apply also to the cargo airship. Therefore, pilot costs are doubled in the following scenarios for any trips that require greater than 8 occupied hours. It is possible that regulations specific to airship operations may emerge in the future however the most conservative approach is to avoid speculation about regulatory outcomes and to assume that existing airplane transport regulations prevail.

7.3.1 Condition 1 Scenarios

The first alternative under this condition assumes the cargo airship replaces conventional aircraft on modified routes and maritime transportation flows are unchanged from the baseline scenario. Because of the limited speed of the cargo airship relative to conventional aircraft, all freight is trans-shipped in Churchill, the origin that is the nearest to the region. A side-effect of this change is a simplification of the re-supply network.

Figure 36 on the following page depicts the freight flows that result from the changes to the NWC's re-supply network. The dotted line between Winnipeg and Churchill depicts the surface inter-modal[12] freight flows between those two points while the solid lines between Churchill and the six CENU communities depict the cargo airship freight flows. The long-dashed lines from Valleyfield to the six communities denote the maritime freight flows which remain fixed according to the baseline scenario. Not illustrated are the SIM flows from Winnipeg, Manitoba to Montreal, Quebec and from Montreal to Valleyfield, Quebec.

[12] Both highway trucking and rail transport are used to move freight from Winnipeg to Churchill.

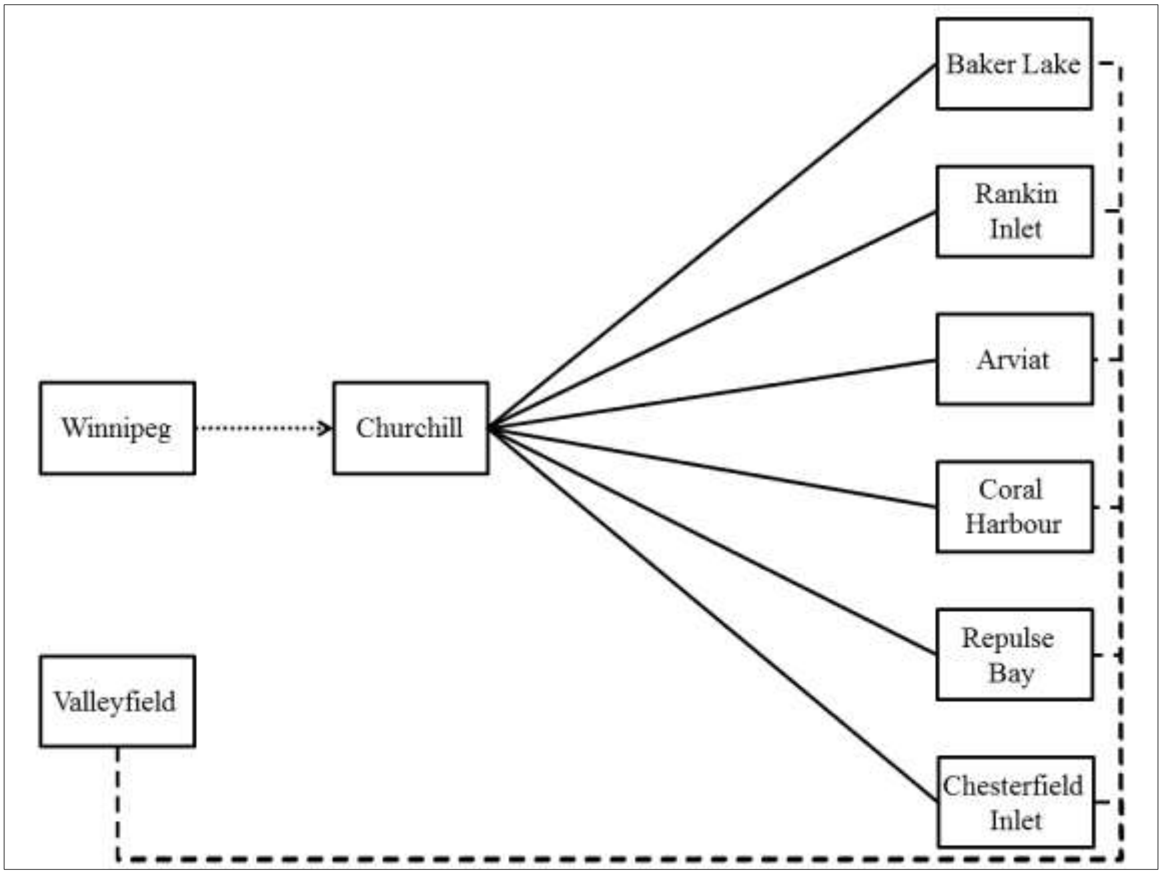

Figure 36 - Diagram of freight flows for CENU cargo airship alternative 1. The dotted lines represent SIM flows, the long-dashed lines represent maritime flows, and the solid lines represent cargo airship flows.

Given the cargo airship's operating characteristics, the average trip requires 11.8 occupied hours. The longest trip in the network is between Churchill and Repulse Bay; it requires 17.3 occupied hours round-trip. Two pilots are needed for all trips to all communities except Arviat. A round-trip to there from Churchill requires 6.2 occupied hours.

Table 40 on the following page describes the freight flows exclusive of the maritime freight flows for this alternative. All surface inter-modal flows occur solely on the Winnipeg-Churchill route. Total cargo airship utilization attributable to re-supplying the CENU region is approximately one million MTK. This is approximately the same level of cargo airship utilization in terms of MTK as the NWON despite the CENU requiring approximately half as much freight. Distances in the CENU region once again play a major role in determining freight transportation requirements.

Table 40 – Cargo airship freight flows for CENU cargo airship alternative 1.

Mode	Origin	Destination	t	km	MTK
Cargo Airship	Churchill	Baker Lake	516	629	324.6
		Rankin Inlet	569.8	466	265.5
		Arviat	864.2	263	227.3
		Coral Harbour	113.1	832	94.1
		Repulse Bay	51.1	955	48.8
		Chesterfield Inlet	64.2	544	34.9
		Total - Airship	2,178.4		995.2
Surface (I-M)	Winnipeg	Churchill	2,178.4	-	-

The cost of the cargo airship system described above is compared to the baseline system that includes trucking, rail, conventional air, and maritime freight transport. Costs are compared at the community level and at the regional level. The calculation for this equation is expressed in equation 19.

Cost difference calculation for alternative 1:

$$D = \frac{[\mathrm{HT} + \mathrm{RL} + \mathrm{CA} + \mathrm{SL}] - [\mathrm{HT} + \mathrm{RL} + \mathrm{AC} + \mathrm{SL}]}{[\mathrm{HT} + \mathrm{RL} + \mathrm{AC} + \mathrm{SL}]}$$

HT: Annual Highway Trucking Costs

RL: Annual Rail Costs

CA: Annual Cargo Airship Costs

SL: Annual Sealift Costs

AC: Annual Conventional Aircraft Costs

Equation 19 - Cost difference between cargo airship system and baseline system in CENU alternative 1.

The second cargo airship alternative under this condition involves a complete restructuring of the CENU region re-supply network. Again, maritime freight flows in this scenario are unchanged from the baseline. The objective in the design of this network is to minimize total transportation costs while also reducing cargo airship flight times so that pilot duty time regulations can be met. The same rule of doubling pilot staffing relative to flight hours applies however this scenario attempts to minimize this occurrence. The network in this alternative is transformed from a point-to-point system to a hub and spoke system in which all of the region's freight flows to a central hub within the region. The cargo airship is used in this case to transport freight from a trans-shipment point outside of the region to the region's hub and then from the hub to each of the communities.

Arviat is selected as the regional hub in this scenario. As Campbell & O'Kelly (2012) note, a large body of literature exists on hub or distribution centre location selection. A model based on the minimum-cost distribution point model found in Harris' paper (1954) confirms Arviat as the ideal hub. This model is a variant of the gravity potential model typically used to determine the force of attraction of markets and supply areas. The model is expressed in equation 20.

$$Min.\ P_i = \left[\sum M_j \times D_{ij}\right] \times LLC_i$$

$P_i =$ Potential for distribution hub i

$M_j =$ Market size (Freight demand) in MT

$D_{ij} =$ Distance between hub i and community j

$LLC_i =$ The lowest landed cost per MT for hub i

Equation 20 - Minimum distribution cost point.

This model incorporates a modification on Harris' (1954) model in that it incorporates the cost of freight transportation into candidate hub communities. The logic is to simultaneously minimize the amount of freight transportation activity in the region and minimize total distribution costs. Without knowing cargo airship transportation costs *a priori,* these costs are assumed to rise proportionally with distance. Variable and fixed transportation costs are minimized by minimizing the intra-regional distances and annual quantity of trips made respectively. The rank-order of the hub candidates based on the output from this analysis is described in table 41. These results confirm the selection of Arviat as the hub community.

Table 41 - Ranking results from CENU hub selection analysis.

Community	% Difference from Arviat
Arviat	-
Rankin Inlet	42.5%
Baker Lake	48.5%
Chesterfield Inlet	106.9%
Coral Harbour	409.8%
Repulse Bay	474.2%

The resulting freight re-supply network is illustrated in figure 37. Freight is transported from Winnipeg to Churchill by surface inter-modal means. The cargo airship ferries the freight to Arviat, and from there the freight is transported by cargo airship to the CENU communities. The use of Arviat as a hub has an additional benefit. By using Arviat as a hub, the quantity of air freight demanded at this store, the highest of all stores in CENU, does not need to be trans-shipped within the region. Maritime freight flows, depicted by the long-dashed lines, remain unchanged.

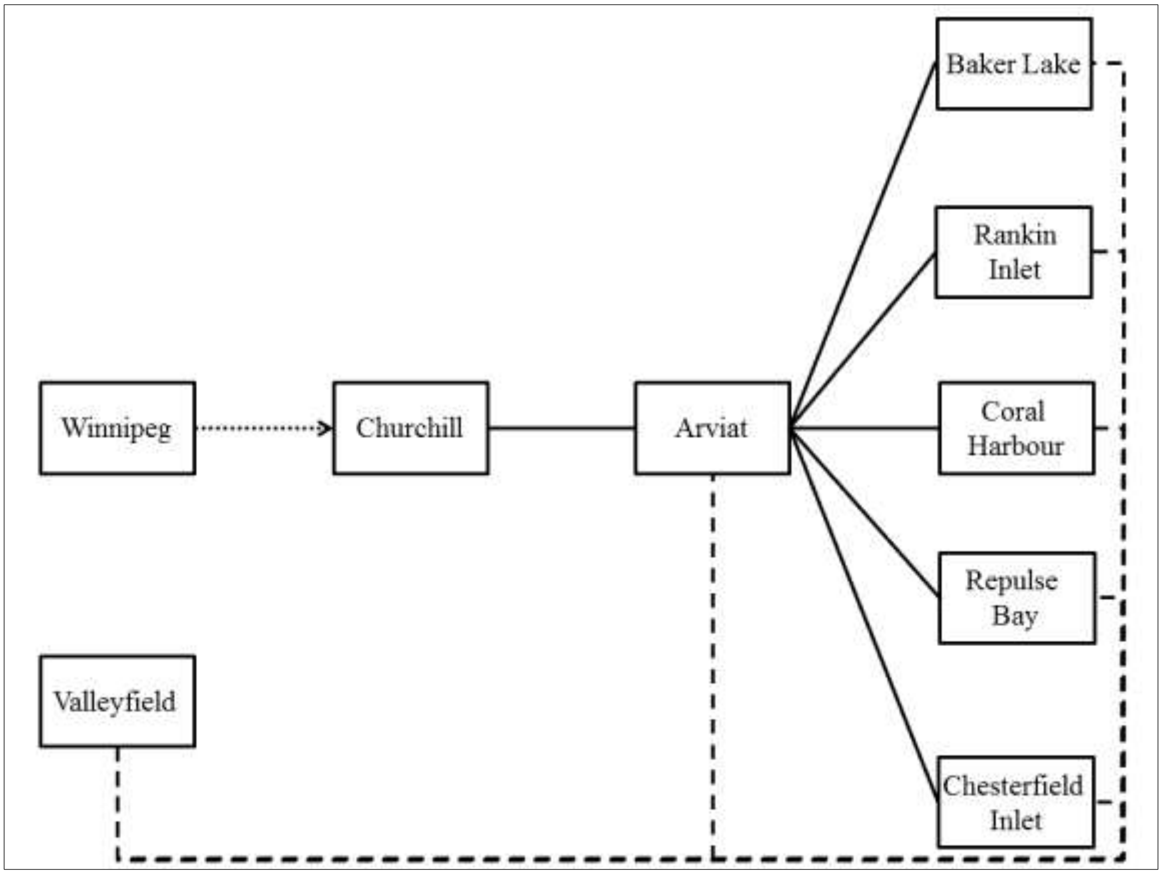

Figure 37 - Diagram of freight flows for CENU cargo airship alternative 2. The dotted lines represent SIM flows, the long-dashed lines represent maritime flows, and the solid lines represent cargo airship flows.

The data in table 42 on the following page describe the freight flows in the network. All freight is shipped from Winnipeg to Churchill by SIM. The cargo airship then transports all freight to Arviat. From there, the cargo airship transports 1,314.2t of freight to the other CENU communities. Approximately one million cargo airship MTKs are needed in total, with more than half occurring between Churchill and Arviat. It is worth noting that the flows from Arviat to Baker Lake and Rankin Inlet account for approximately 71% of total intra-regional airship MTK, destinations that require 7.9 and 5.4 occupied hours from Arviat respectively. In other words, the majority of the cargo airship travel is to destinations well within the regulated pilot duty time limits imposed by current regulations. The hub and spoke system therefore achieves the objective of minimizing two-pilot flight crews.

Table 42 – Cargo airship freight flows for CENU cargo airship alternative 2.

Mode	Origin	Destination	t	km	MTK
Cargo Airship	Arviat	Baker Lake	516	371	191.4
		Rankin Inlet	569.8	217	123.6
		Coral Harbour	113.1	647	73.1
		Repulse Bay	51.1	716	36.6
		Chesterfield Inlet	64.2	305	19.6
		Total - Airship	1,314.2		444.3
Cargo Airship	Churchill	Arviat	2,178.4	263	572.9
		Total – Cargo Airship			1,017.2
Surface (I-M)	Winnipeg	Churchill	2,178.4	-	-

Although the freight transportation system is restructured in alternative 2, the cost comparison calculation is the same as for alternative 1. The same modes are used in this alternative as in alternative 1 with altered routing. The formula for calculating the cost difference is expressed in equation 21.

Cost difference calculation for alternative 2:

$$D = \frac{[\mathrm{HT} + \mathrm{RL} + \mathrm{CA} + \mathrm{SL}] - [\mathrm{HT} + \mathrm{RL} + \mathrm{AC} + \mathrm{SL}]}{[\mathrm{HT} + \mathrm{RL} + \mathrm{AC} + \mathrm{SL}]}$$

HT: Annual Highway Trucking Costs
RL: Annual Rail Costs
CA: Annual Cargo Airship Costs
SL: Annual Sealift Costs
AC: Annual Conventional Aircraft Costs

Equation 21 - Cost difference between cargo airship system and baseline system in CENU alternative 2.

One point to note about these and the baseline scenarios is that some of the maritime freight arrives directly from vendors to the staging area in Valleyfield. Approximately

80% of the food and 20% of the GM arrives this way. The balance is shipped from Winnipeg, Manitoba through the SIM path to Valleyfield, Quebec. The rates assigned to these flows are adjusted to compensate for this.

7.3.2 Condition 2 Scenarios

The two scenarios in this condition assume all maritime freight is shifted to the cargo airship. Alternative 3 is relatively similar to the first scenario in the first condition. All freight is transported from Winnipeg to Churchill, and from Churchill all freight is transported to the CENU communities by airship. Pilot costs are doubled in this scenario for any flights with total trip times over 8 hours. The re-supply network for this scenario is illustrated in figure 38.

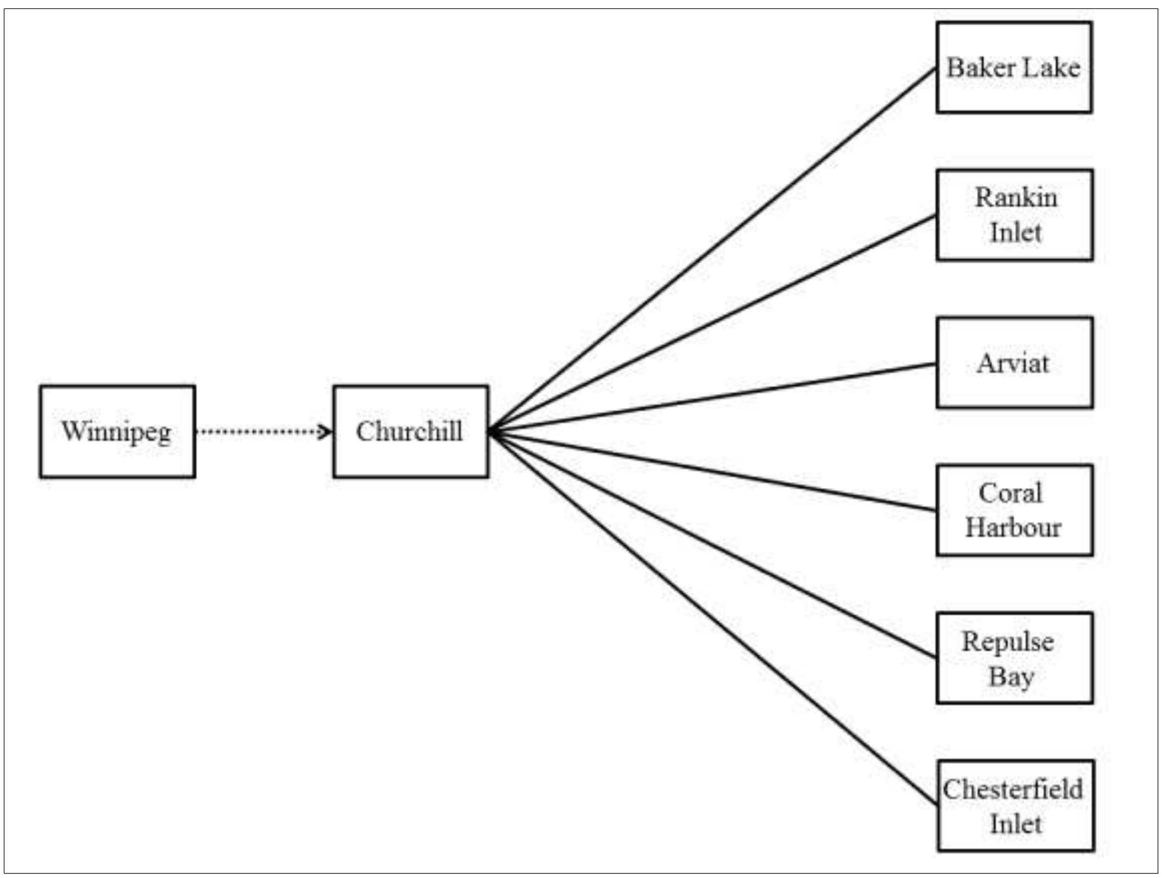

Figure 38 - Re-supply network diagram for CENU cargo airship alternative 3. The dotted lines represent SIM flows and the solid lines represent cargo airship flows.

The resulting freight flows are described in table 43. The communities are ordered in this table by MTK (1,000's), from highest to lowest. The additional freight quantity results in a significant increase in airship utilization in comparison with the first scenario under the first condition. Total MTK increases from slightly less than one million MTK to 1.7 million MTK, an increase of 72.8%. The additional freight quantity also slightly changes the ordering of stores in terms of total MTK. Coral Harbour and Arviat switch places, with the former accounting for a greater number of MTK than the latter.

Table 43 – Cargo airship freight flows for CENU cargo airship alternative 3.

Mode	Origin	Destination	t	km	MTK
Cargo Airship	Churchill	Baker Lake	872.4	629	548.7
		Rankin Inlet	919.4	466	428.4
		Coral Harbour	358.5	832	298.3
		Arviat	878.4	263	231.0
		Repulse Bay	157.1	955	150.0
		Chesterfield Inlet	117.2	544	63.8
		Total - Airship	3,303.0		1,720.2
Surface (I-M)	Winnipeg	Churchill	3,303.0	-	-

The cost comparison for alternative 3 is between the cargo airship system without maritime transportation and the baseline system. The formula for calculating the cost differential is expressed in equation 22.

Cost difference calculation for alternative 3:

$$D = \frac{[\mathrm{HT + RL + CA}] - [\mathrm{HT + RL + AC + SL}]}{[\mathrm{HT + RL + AC + SL}]}$$

HT: Annual Highway Trucking Costs
RL: Annual Rail Costs
CA: Annual Cargo Airship Costs
SL: Annual Sealift Costs
AC: Annual Conventional Aircraft Costs

Equation 22 - Cost difference between cargo airship system and baseline system in CENU alternative 3.

Alternative 4 involves a switch to a hub and spoke system whereby the cargo airship is used to ferry freight into a regional hub and as an intra-regional freight feeder vehicle. Because the maritime freight flows alter the quantities of freight shipped to each CENU community, it is necessary to determine which of the communities should serve as the hub. The rank-order of the communities based on the output from this analysis is presented in table 44. Arviat is again determined to be the optimal hub, and the path Winnipeg – Churchill – Arviat is the least-cost path for delivering freight to the regional hub.

Table 44 - Ranking results from CENU hub selection analysis 2.

Community	% Difference from Arviat
Arviat	-
Rankin Inlet	16.3%
Baker Lake	46.3%
Chesterfield Inlet	54.7%
Coral Harbour	244.7%
Repulse Bay	288.9%

The resulting freight re-supply network is identical to the hub and spoke network model in the second scenario with the exception that maritime freight flows are not present. This is illustrated in figure 39. Freight is transported from Winnipeg to Churchill by SIM. Freight is then transported from Churchill to Arviat and from Churchill to each community by cargo airship.

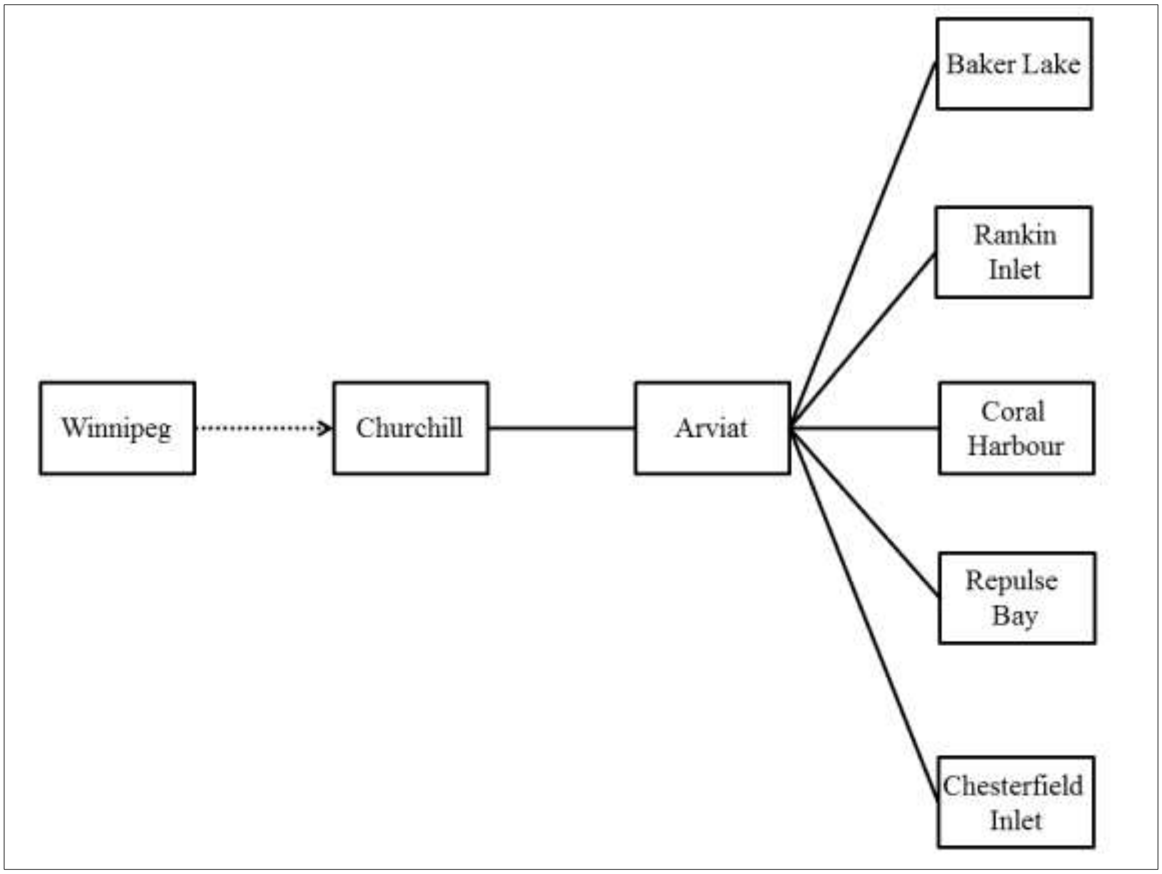

Figure 39 - Re-supply network diagram for CENU cargo airship alternative 4. The dotted lines represent SIM flows and the solid lines represent cargo airship flows.

Table 45 – Freight flows for CENU cargo airship alternative 4.

Mode	Origin	Destination	t	km	MTK
Cargo Airship	Arviat	Baker Lake	872.4	371	323.7
		Coral Harbour	358.5	647	231.9
		Rankin Inlet	919.4	217	199.5
		Repulse Bay	157.1	716	112.5
		Chesterfield Inlet	117.2	305	35.7
		Total - Airship	2,424.6		903.3
Cargo Airship	Churchill	Arviat	3,303.0	263	868.7
		Total – Cargo Airship			1,772.0
Surface (I-M)	Winnipeg	Churchill	3,303.0	-	-

The freight flows for this alternative are described in table 45. Total cargo airship MTK is approximately 1.7 million with a near 50/50 split between the flows from Churchill to the hub and from the hub to the communities. Only the trips to Coral Harbour and Repulse Bay require a two-pilot flight crew. Only one pilot is required for all other trips in this hub and spoke system.

The cost comparison for alternative 4 is identical to alternative 2 with the exception that maritime costs are not included in the cargo airship system costs. Cost differentials are calculated for each community and at the regional level using equation 23.

Cost difference calculation for alternative 4:

$$D = \frac{[\text{HT} + \text{RL} + \text{CA}] - [\text{HT} + \text{RL} + \text{AC} + \text{SL}]}{[\text{HT} + \text{RL} + \text{AC} + \text{SL}]}$$

HT: Annual Highway Trucking Costs
RL: Annual Rail Costs
CA: Annual Cargo Airship Costs
SL: Annual Sealift Costs
AC: Annual Conventional Aircraft Costs

Equation 23 - Cost difference between cargo airship system and baseline system in CENU alternative 4.

7.4 CENU Results

CENU alternative 1 assumes all air freight is transported by cargo airship while maritime freight flows remain fixed. In addition, the freight transported by cargo airship is shipped by truck to Thompson, by rail to Churchill, and into the CENU region by cargo airship. Total cargo airship operational requirements are summarized in table 46. Nearly one million MTK are needed to serve the region. A total of 347.6 block hours and 404.4 occupied hours are accrued over a total of 43.6 trips. Arviat, Baker Lake, and Rankin Inlet account for almost three quarters of cargo airship trips, while Chesterfield Inlet, Coral Harbour, and Repulse bay each require between one and two trips per year. Note that trips to Baker Lake, Chesterfield Inlet, Coral Harbour, and Repulse Bay all require a two-pilot flight crew.

Table 46 - Summary of cargo airship activity for CENU alternative 1.

Destination	t	km	MTK	Trips	BH	OH	OH/Trip
Arviat	864.2	263	227.3	17.3	84.8	107.3	6.2
Baker Lake	516.0	629	324.6	10.3	110.2	123.6	12.0
Chesterfield Inlet	64.2	544	34.9	1.3	12.2	13.9	10.7
Coral Harbour	113.1	832	94.1	2.3	32.2	35.2	15.3
Rankin Inlet	569.8	466	265.5	11.4	92.3	107.2	9.4
Repulse Bay	51.1	955	48.8	1.0	15.9	17.2	17.2
Total	2,178.4		995.2	43.6	347.6	404.4	

t: Annual freight quantity (T).
km: Distance between origin and destination.
MTK: Annual cargo airship MTK.
Trips: Annual cargo airship trips.
BH: Annual cargo airship block hours.
OH: Annual cargo airship block hours.

Table 47 - Cost comparison results for CENU alternative 1.

Community	SIM t	SLFT CTR	CA t	*D*
Arviat	864.2	5	864.2	-20.9%
Baker Lake	516	38	516	-29.9%
Chesterfield Inlet	64.2	5	64.2	-26.4%
Coral Harbour	113.1	25	113.1	-48.8%
Rankin Inlet	569.8	38	569.8	-24.4%
Repulse Bay	51.1	11	51.1	-35.6%
Total	2,178.4	122	2,178.4	-29.8%

SIM t: Surface intermodal freight quantity (t).
SLFT CTR: Maritime container quantity. The shipper is charged per container.
CA t: Cargo airship freight quantity (t).
D: Cost difference between CENU 1 and the baseline CENU system.

The cost impact of the cargo airship in alternative 1 is summarized in table 47. These results are illustrated on a conceptual map of the CENU region shown in figure 40 on the following page. The region as a whole experiences a cost reduction of 29.8% per year. The greatest cost savings is experienced by Coral Harbour (48.8%) while Arviat experiences the least (20.9%). In dollar terms, Baker Lake experiences the greatest reduction in annual transportation costs while Chesterfield Inlet experiences the least.

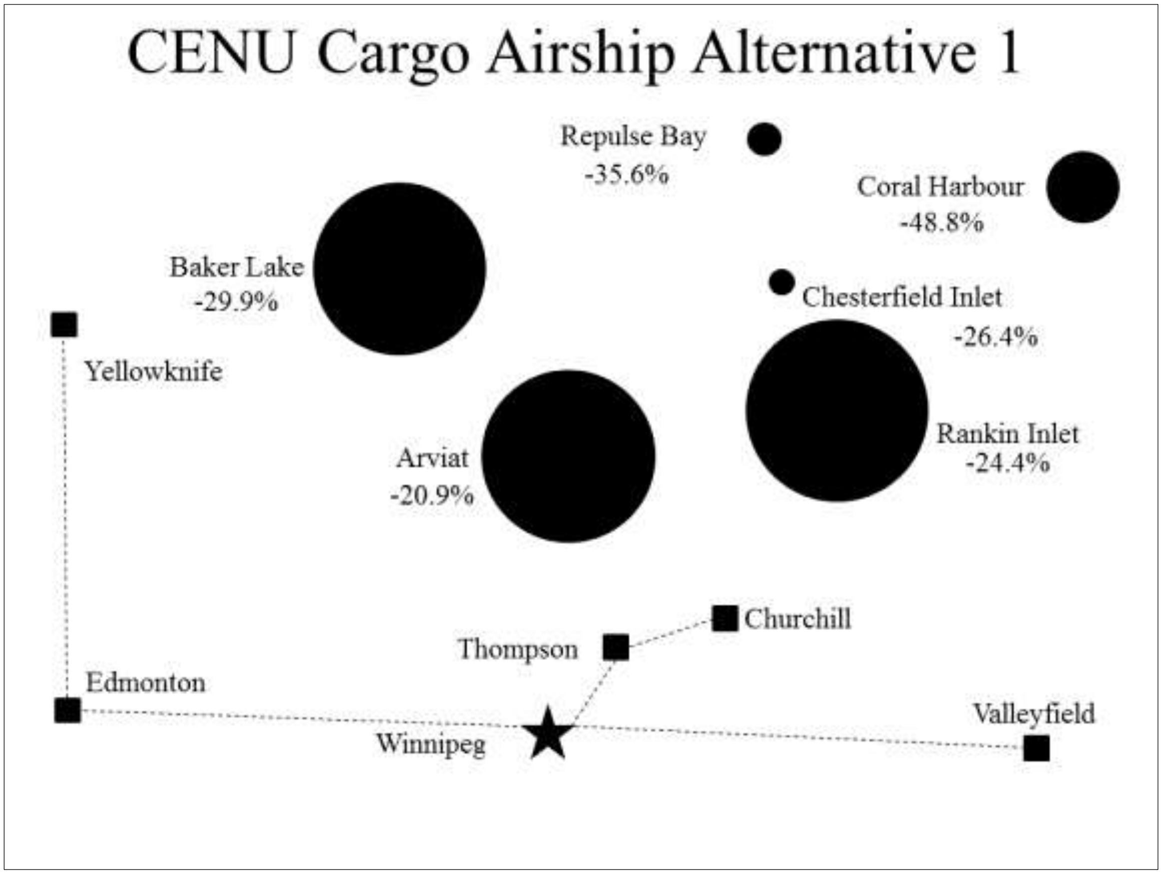

Figure 40 - Map of results from CENU cargo airship alternative 1.The percentages indicate the proportional cost differential between the baseline CENU freight transportation system costs and cargo airship alternative 1 in which the cargo airship carries all freight to each community from Churchill and maritime freight flows remain fixed. The percentages shown in this map correspond to *D* shown in table 47.

Alternative 2 is the hub and spoke system with maritime freight flows. Total cargo airship operational requirements are summarized in table 48. Note that the flows to Arviat originate in Churchill while the flows to other destinations originate in Arviat. Total block hours and occupied hours are 372.9 and 463.8 respectively. Note that the only two-pilot crews required in this alternative are for the 2.3 trips to Coral Harbour and the one trip to Repulse Bay.

Table 48 - Summary of cargo airship activity for CENU alternative 2.

Destination	t	km	MTK	Trips	BH	OH	OH/Trip
Arviat	2178.4	263	572.9	43.6	213.6	270.3	6.2
Baker Lake	516	371	191.4	10.3	68.0	81.4	7.9
Chesterfield Inlet	64.2	305	19.6	1.3	7.2	8.8	6.8
Coral Harbour	113.1	647	73.1	2.3	25.3	28.3	12.3
Rankin Inlet	569.8	217	123.6	11.4	46.7	61.6	5.4
Repulse Bay	51.1	716	36.6	1	12.1	13.4	13.4
Total			1,017.2	69.9	372.9	463.8	

t: Annual freight quantity (t).
km: Distance between origin and destination.
MTK: Annual cargo airship MTK.
Trips: Annual cargo airship trips.
BH: Annual cargo airship block hours.
OH: Annual cargo airship block hours.
OH/Trip: Number of occupied hours per cargo airship trip.

The cost impact of the cargo airship in CENU alternative 2 is summarized in table 49 on the following page. These results are also illustrated on a conceptual map of the CENU region shown in figure 41 on page 127. The largest cost changes between alternative 2 and the baseline scenario, shown in the D_1 column, occurs in Arviat. Total transportation costs to Arviat increase by 45.1%. This is offset by cost savings of between 40% and 50% in all other communities leading to an overall cost reduction of 26.1%.

The D_2 column in table 49 shows the results of the cost comparison between CENU alternative 2 and alternative 1. This illustrates the cost differential between direct flights from Churchill using mainly two-pilot crews and the hub and spoke system that avoids this occurrence. Transportation costs to Arviat are 83.5% higher in alternative 2 than in alternative 1 while transportation costs drop in all other communities. The net effect, however, is that alternative 2 is 5.3% more costly than alternative 1.

Table 49 - Cost comparison results for CENU alternative 2.

Community	SIM t	SLFT CTR	AC t	CA t	D_1	D_2
Arviat	864.2	5	864.2	0	45.1%	83.5%
Baker Lake	516	38	516	516	-43.5%	-19.4%
Chesterfield Inlet	64.2	5	64.2	64.2	-40.6%	-19.3%
Coral Harbour	113.1	25	113.1	113.1	-52.9%	-8.0%
Rankin Inlet	569.8	38	569.8	569.8	-41.0%	-21.9%
Repulse Bay	51.1	11	51.1	51.1	-41.8%	-9.6%
Total	2,178.4	122	2,178.4		-26.1%	5.3%

SIM t: Surface intermodal freight quantity (t).
SLFT CTR: Maritime container quantity. The shipper is charged per container.
AC t: Conventional aircraft freight quantity (t).
CA t: Cargo airship freight quantity (t).
D_1: Cost difference between CENU 2 and the baseline CENU system.
D_2: Cost difference between CENU 2 and CENU 1.

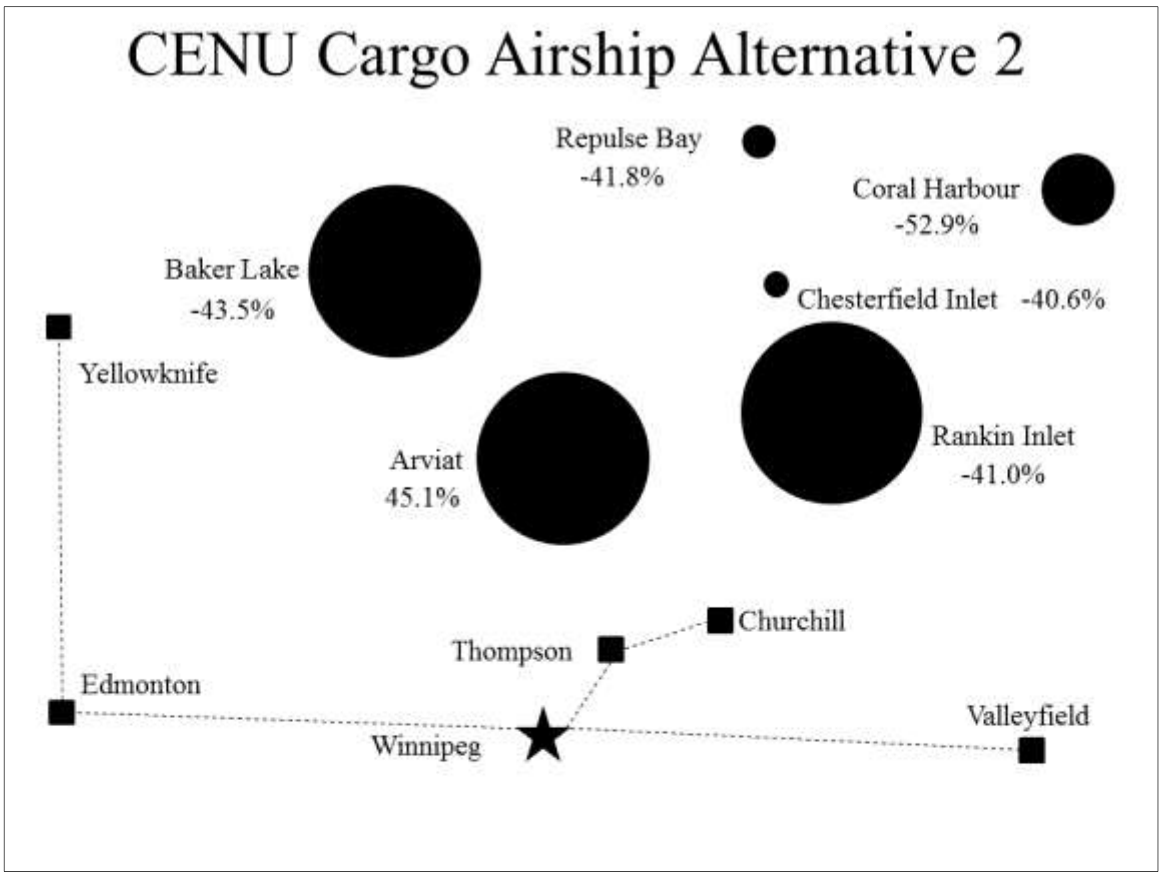

Figure 41 - Map of results from CENU cargo airship alternative 2.The percentages indicate the proportional cost differential between the baseline CENU freight transportation system costs and cargo airship alternative 2 in which the cargo airship carries freight to and from a hub in Arviat. The percentages shown in this map correspond to D_1 shown in table 49.

Total cargo airship requirements for CENU alternative 3 are summarized in table 50. Cargo airship MTK increases to 1.7 million as a result of diverting maritime freight flows to this mode. This represents an approximate doubling of cargo airship MTK from alternative 1. Freight re-supply requires 66.0 cargo airship trips over 593.1 block hours and 679.0 occupied hours annually. Arviat, Baker Lake, Rankin Inlet account for the greatest proportion of annual cargo airship trips. Coral Harbour, although needing relatively few trips per year, requires nearly an equal number of block hours and occupied hours as these communities because of the distance between Churchill and that community. Trips to Baker Lake, Chesterfield Inlet, Coral Harbour, and Repulse Bay require a two-pilot flight crew.

Table 50 - Summary of cargo airship activity for CENU alternative 3.

Destination	t	km	MTK	Trips	BH	OH	OH/Trip
Arviat	878.4	263	231.0	17.6	86.2	109.1	6.2
Baker Lake	872.4	629	548.7	17.4	186.2	208.8	12.0
Chesterfield Inlet	117.2	544	63.8	2.3	21.6	24.6	10.7
Coral Harbour	358.5	832	298.3	7.2	100.8	110.2	15.3
Rankin Inlet	919.4	466	428.4	18.4	149.0	173.0	9.4
Repulse Bay	157.1	955	150.0	3.1	49.3	53.3	17.2
Total	3,303.0		1,720.2	66.0	593.1	679.0	

The cost impact of the cargo airship is summarized in table 51. The results are also illustrated in a conceptual map of the CENU region shown in figure 42 on page 129. Despite not using maritime freight transport, the cargo airship system affords a total transportation cost savings of 16.4%. The greatest savings are experienced by Arviat (23.6%) and Coral Harbour (19.2%) while the costs to Repulse Bay increase by 4.7%.

Table 51 - Cost comparison results for CENU alternative 3.

Community	SIM t	CA t	*D*
Arviat	878.4	878.4	-23.6%
Baker Lake	872.4	872.4	-15.8%
Chesterfield Inlet	117.2	117.2	-10.2%
Coral Harbour	358.5	358.5	-19.2%
Rankin Inlet	919.4	919.4	-15.2%
Repulse Bay	157.1	157.1	4.7%
Total	3,303.0	3,303.0	-16.4%

SIM t: Surface intermodal freight quantity (t).
CA t: Cargo airship freight quantity (t).
D: Cost difference between CENU 3 and the baseline CENU system.

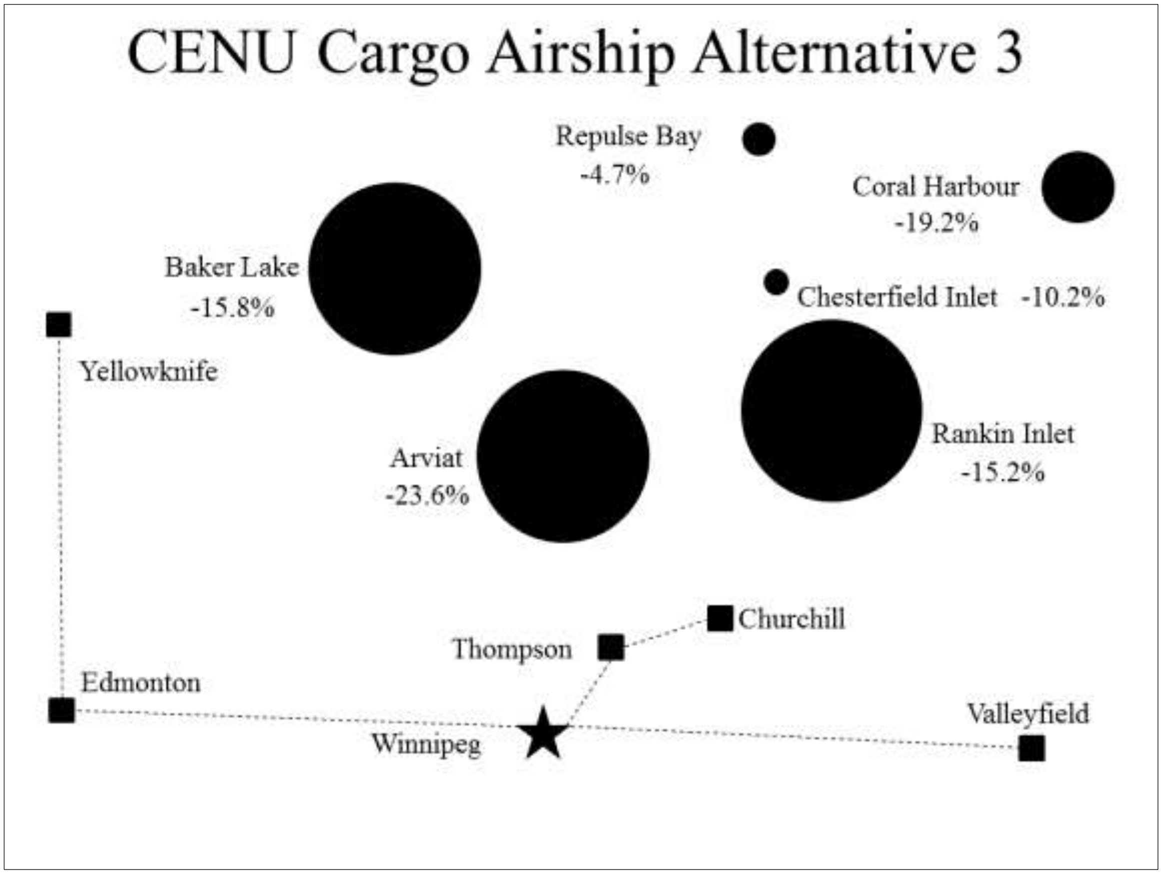

Figure 42 - Map of results from CENU cargo airship alternative 3.The percentages indicate the proportional cost differential between the baseline CENU freight transportation system costs and cargo airship alternative 3 in which the cargo airship carries freight to each community from Churchill and no maritime freight is used. The percentages shown in this map correspond to D_1 shown in table 51.

Finally, total cargo airship requirements for alternative 4 are summarized in table 52. Total cargo airship MTK requirements are 1.1 million. In total, the cargo airship is needed for 114.5 trips, 643.49 block hours, and 792.42 occupied hours per year. Trips to Coral Harbour and Repulse Bay require a two-pilot crew. These communities require 10.3 trips and 130.1 occupied hours in total.

Table 52 - Summary of cargo airship activity for CENU alternative 4.

Destination	t	km	MTK	Trips	BH	OH	OH/Trip
Arviat	3,303.0	263	231.0	66.1	323.9	409.8	6.2
Baker Lake	872.4	371	323.7	17.4	114.8	137.5	7.9
Chesterfield Inlet	117.2	305	231.9	2.3	12.7	15.6	6.8
Coral Harbour	358.5	647	199.5	7.2	79.2	88.6	12.3
Rankin Inlet	919.4	217	112.5	18.4	75.4	99.4	5.4
Repulse Bay	157.1	716	35.7	3.1	37.5	41.5	13.4
Total	2,424.6		1,134.3	48.4	319.6	382.6	

Results for this alternative are summarized in table 53. Results are also illustrated in a conceptual map of the CENU region shown in figure 43 on page 131. Total cost savings across the region amounts to 9.2%. Arviat experiences a cost increase of 98.3% but this is offset in total by cost savings in all other communities. The transportation cost savings from diverting all freight to the cargo airship are lower than when maritime freight transportation is used. Alternative 4 is also 8.6% more costly than alternative 3.

Table 53 - Cost comparison results for CENU alternative 4.

Community	SIM t	AC t	CA t	D_1	D_2
Arviat	864.2	864.2	0	98.3%	159.4%
Baker Lake	516	516	872.4	-38.7%	-27.3%
Chesterfield Inlet	64.2	64.2	117.2	-35.4%	-28.0%
Coral Harbour	113.1	113.1	358.5	-32.1%	-15.9%
Rankin Inlet	569.8	569.8	919.4	-42.0%	-31.6%
Repulse Bay	51.1	51.1	157.1	-14.4%	-18.3%
Total	3,303.0	3,303.0	2424.6	-9.2%	8.6%

SIM t: Surface intermodal freight quantity (t).
AC t: Conventional aircraft freight quantity (t).
CA t: Cargo airship freight quantity (t).
D_1: Cost difference between CENU 4 and the baseline CENU system.
D_2: Cost difference between CENU 4 and CENU 3.

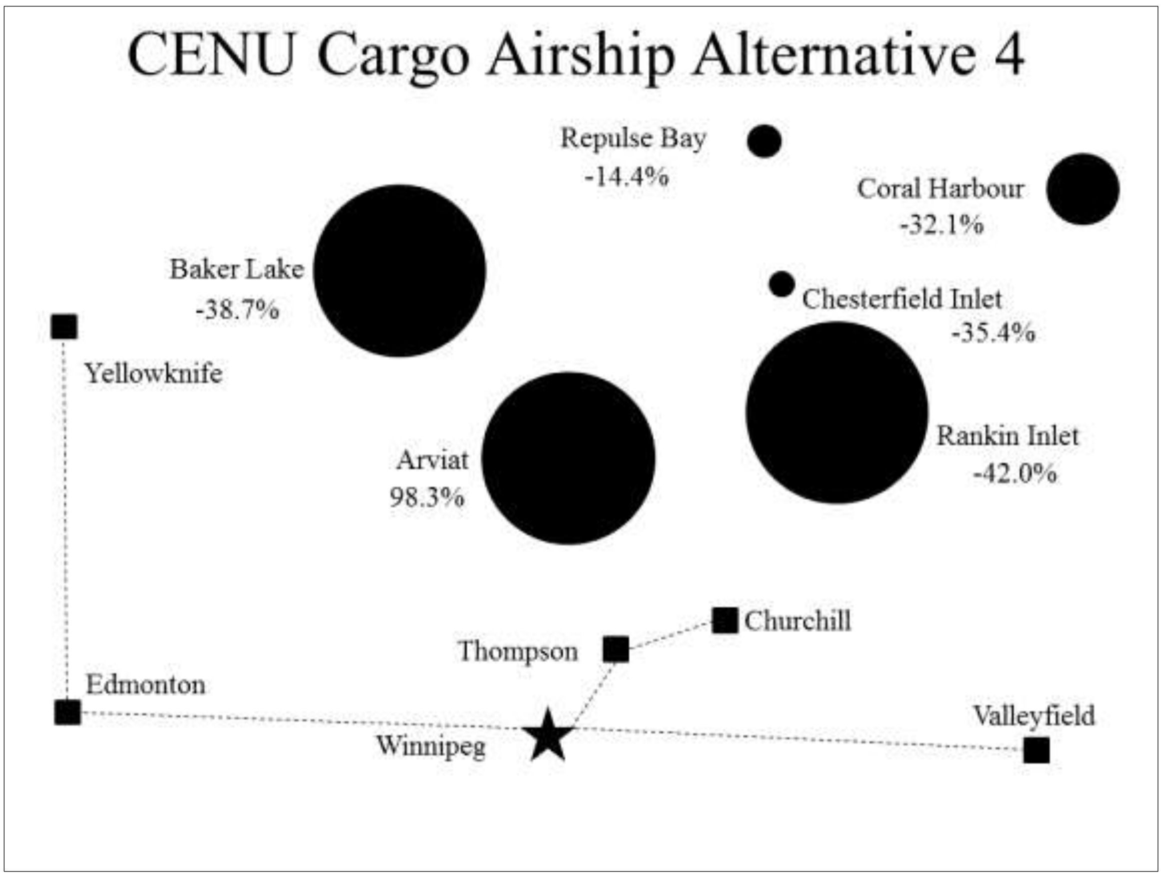

Figure 43 - Map of results from CENU cargo airship alternative 4.The percentages indicate the proportional cost differential between the baseline CENU freight transportation system costs and cargo airship alternative 4 in which the cargo airship carries freight to and from a hub in Arviat and no maritime freight is used. The percentages shown in this map correspond to D_1 shown in table 53.

Two within-case analyses are conducted for the CENU region. A comparison between alternative 1 and alternative 3 and between alternative 2 and alternative 4 reveals the cost differential between cargo airship-only freight transportation systems and those that include maritime freight transportation. These analyses also illustrate the difference between using and not using maritime freight transportation in a system where the cargo airship operates out of Churchill or out of Arviat.

The results from the first within-case comparison are summarized in table 54. The net impact on the region of not using maritime freight transportation is an increase in transportation costs of 13.4% when the cargo airship is operated out of Churchill. Coral Harbour and Repulse Bay, the two communities the most distant from the cargo airship trans-shipment point in Churchill experience the greatest cost increases (29.5% and 30.9% respectively). Arviat experiences a decrease in annual freight transportation costs of 2.6% when the cargo airship is used exclusively. In summary, annual transportation costs are minimized when the cargo airship is used in conjunction with maritime freight transportation when all cargo airship freight flows originate in Churchill.

Table 54 - Cost savings (vs. baseline) comparison between CENU alternative 1 and CENU alternative 3.

Trans-ship	Community	*D* CENU 1	*D* CENU 3	Difference
Churchill	Arviat	-20.9%	-23.6%	-2.6%
	Baker Lake	-29.9%	-15.8%	14.1%
	Chesterfield Inlet	-26.4%	-10.2%	16.2%
	Coral Harbour	-48.8%	-19.2%	29.5%
	Rankin Inlet	-24.4%	-15.2%	9.1%
	Repulse Bay	-35.6%	4.7%	30.9%
	Total	-29.8%	-16.4%	13.4%

Results from the within-case comparison between alternatives 2 and 4 are summarized in table 55. Results again reveal that transportation costs are minimized when the cargo airship is utilized in conjunction with maritime freight transportation. The overall cost savings differential between the two alternatives is 16.9% in favour of alternative 2. The greatest differentials are for Arviat (53.2%), Coral Harbour (20.8%), and Repulse Bay (27.3%).

Table 55 - Cost savings (vs. baseline) comparison between CENU alternative 2 and CENU alternative 4.

Trans-ship	Community	*D* CENU 2	*D* CENU 4	Difference
Arviat	Arviat	45.1%	98.3%	-53.2%
	Baker Lake	-43.5%	-38.7%	4.8%
	Chesterfield Inlet	-40.6%	-35.4%	5.2%
	Coral Harbour	-52.9%	-32.1%	20.8%
	Rankin Inlet	-41.0%	-42.0%	-1.1%
	Repulse Bay	-41.8%	-14.4%	27.3%
	Total	-26.1%	-9.2%	16.9%

Both within-case comparisons reveal that the greatest cost savings are achieved by using the cargo airship in conjunction with maritime transport. They also demonstrate that the greatest transportation cost savings are achieved when the cargo airship is operated directly from Churchill to each community rather than the hub and spoke system. In other words, the additional cost of employing a two-pilot crew is lower than the additional cost of indirect freight routing.

Chapter 9: Comparison of Results Across Regions

Table 56 - Cost comparison results at the region level.

Alternative	Baseline	% Difference
ESLW 1	**ESLW 0**	**-31.6%**
ESLW 2	ESLW 0	-12.5%
ESLW 2	ESLW AC	-35.2%
ESLW AC	ESLW 0	35.1%
NWON 1	**NWON 0**	**-38.3%**
NWON 2	NWON 0	-34.0%
NWON 2	NWON AC	-38.0%
NWON AC	NWON 0	6.5%
CENU 1	**CENU 0**	**-29.8%**
CENU 2	CENU 0	-26.1%
CENU 3	CENU 0	-16.4%
CENU 4	CENU 0	-9.2%

ESLW 0: Baseline ESLW transportation system.
ESLW 1: ESLW cargo airship alternative 1.
ESLW 2: ESLW cargo airship alternative 2.
ESLW AC: ESLW conventional aircraft-only system.
NWON 0: Baseline NWON transportation system.
NWON 1: NWON cargo airship alternative 1.
NWON 2: NWON cargo airship alternative 2.
NWON AC: NWON conventional aircraft-only system.
CENU 0: Baseline CENU transportation system.
CENU 1: CENU cargo airship alternative 1.
CENU 2: CENU cargo airship alternative 2.
CENU 3: CENU cargo airship alternative 3.
CENU 4: CENU cargo airship alternative 4.

The results for all three regions are summarized in table 56.There are slight differences in the cost savings between each region. For example, the cost difference between the cargo airship-only system and the combined winter road trucking and cargo airship system in the ESLW is significantly higher than the difference between these two systems in the NWON. The ESLW communities are proportionally more dependent on winter road trucking than the NWON communities. Regions that depend to a greater degree on winter road trucking would experience lower transportation cost savings by shifting all freight to a cargo airship in comparison with regions that are less dependent on winter road trucking.

The results for all regions also provide evidence that the cargo airship possesses a relative economic advantage over conventional aircraft. This is made most obvious in the ESLW and NWON alternatives where either the cargo airship or conventional aircraft transport all freight. Conventional aircraft-only freight transportation systems are 35-38% more expensive than the baseline systems serving these two regions while the cargo airship-only system is less expensive than the baseline. The general trend is that the more proportionally dependent on conventional aircraft a region is, the greater the savings from switching to cargo airships will be.

Comparison between the results from the CENU region and the other two regions shows that distance affects potential cost savings negatively. The CENU communities are the most reliant on air transport however replacing conventional aircraft with a cargo airship produces lower cost savings than in the other two regions. Another factor at play in this region is that larger and more efficient aircraft are used in comparison with the ESLW and NWON regions.

Analysis of transportation cost behaviour as distance increases provides further insight into the relative cost performance of each mode. Figure 44 illustrates the cost curves for the cargo airship, conventional aircraft, winter road trucking, and highway trucking in dollars per metric tonne over distance in kilometers. The cost curves for existing modes of transportation are linear approximations derived from the dataset provided by the shipper. The cargo airship cost curve is derived from the operating cost model provided by the developer. All of the cost curves are plotted within the range of distances included in the original dataset. The maritime cost curve was left out of this analysis because the data shows this is a flat rate.

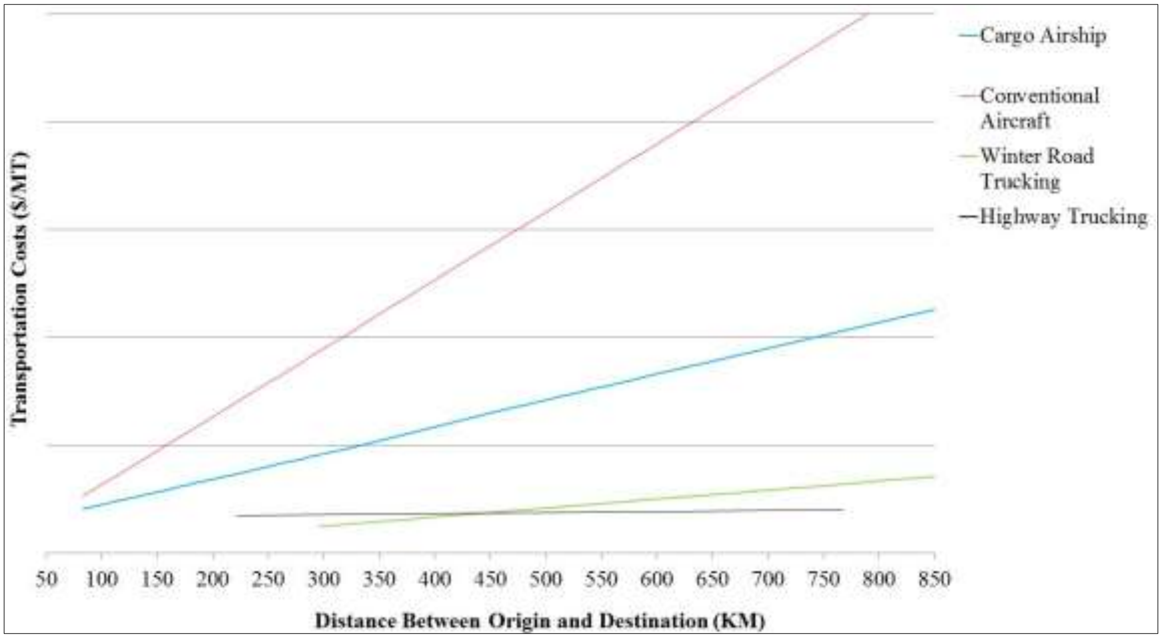

Figure 44 - Cost curves (In $/t) for the cargo airship, conventional aircraft, winter road trucking, and highway trucking over distance (km). The Y-axis has been removed for confidentiality purposes.

The general trend that the cargo airship is most competitive when used in conjunction with trucking is reflected in figure 44. Both highway and winter road trucking are less costly than the cargo airship. The relative economic advantage of the cargo airship over conventional aircraft is also evident. Conventional aircraft costs rise rapidly as distances increase while cargo airship costs increase at a much lower rate. Generally, the cargo airship is the lower cost alternative to conventional aircraft but higher cost than surface modes of freight transportation at any distance.

In summary, the results from the within-case analyses are reflected in the between-case analyses. The cargo airship possesses a cost advantage over conventional aircraft serving remote regions in northern Canada. This is true for all air transport distances encountered in the case regions (Between 83 and 1,955 kilometers). Lastly, the cargo airship affords the greatest direct transportation cost savings when used in conjunction with surface modes of transportation.

Chapter 10: Conclusion

10.1 Discussion of Results

The results from the preceding analyses reveal that the proposed cargo airship design does possess an economic advantage in serving isolated regions in northern Canada relative to existing modes of transportation. Employing cargo airships as part of a multi-modal freight transportation system to serve isolated regions in northern Canada could reduce freight transportation costs by 29.8% and 38.3% relative to each region's existing freight transportation system. These cost savings are based on direct freight transportation costs alone, and achieving them requires the conditions assumed in the analysis to prevail.

Cost savings are greatest in regions that are increasingly dependent on conventional aircraft. All of the regions analyzed in this research are highly dependent on conventional aircraft for freight re-supply therefore the economic advantage of the cargo airship is pronounced. The greatest cost savings are achieved by using the airship in conjunction with seasonally available modes of surface transportation.

The long-term viability of winter road trucking is questionable given the warming climate. Freight transportation costs would rise by approximately 30% if conventional aircraft are used exclusively for re-supply. Conversely, the availability of cargo airships in such a future scenario would afford cost savings of between 12.5% and 38.3% depending on the region. The ESLW region in Manitoba will be more severely impacted by the loss of winter roads than would the NWON because the former region is more reliant on this mode of transportation than the latter.

10.2 Limitations

These findings are limited by the assumptions made in the preceding analyses. Achieving these cost savings depends on the airship being capable of operating 7,200 hours per year. There must be a large enough freight transportation market willing to pay for these operating hours and climatic conditions must be favourable to achieve this level of utilization. In addition, the accuracy of these findings is dependent on the accuracy of the cost estimates provided by the cargo airship developer. Limitations also arise from the limited focus on one shipper and three regions in northern Canada. Additional research is recommended to test the validity of the assumptions made in this research and to develop a more accurate understanding of the economic impact of employing cargo airships to serve isolated northern Canadian regions.

10.3 Recommendations for Future Research

This thesis provides a foundation for a multitude of research topics. These can be divided into topics that are internal and external to the analyses conducted in this thesis. Internal research topics are those that relate to increasing the depth of understanding of the components of the cost comparison analyses. These include an investigation into and inclusion of additional logistics costs, climatic research, freight volumetric data, cargo airship engineering feasibility studies, and cargo airship routing alternatives. External topics increase the breadth of the analyses. These include research into the operations of other shippers that serve isolated northern Canadian regions, passenger travel demand, cargo airship design and capacity alternatives, and impacts on the regions studied.

The availability of cargo airship freight transportation service would have impacts on shippers that extend beyond direct transportation cost savings. Data are not available that described freight handling costs at terminals, losses due to freight damage and spoilage, inventory holding costs, or additional administrative and operational costs associated with seasonal freight transportation availability. These costs must be included in costing analyses to determine whether the cargo airship is indeed best employed in conjunction with seasonally available modes of freight transportation. For example, the NWC incurs costs from leasing and operating temporary warehouse capacity, inventory holding costs from stockpiling non-perishable goods over a full year, and additional administrative costs in order to take advantage of winter road trucking and maritime transport when they are available. The impact of the elimination of these costs is worth exploring.

Freight volumetric data are not available for these analyses. There is a great variety in the weight density of goods shipped by the NWC to destinations in the case regions. One of the advantages of cargo airships over existing aircraft is that they are significantly less limited in volume capacity. The inclusion of volumetric data would illustrate the impact that greater volumetric capacity would have on the NWC's operations.

The route modelling employed in the preceding analyses is the simplest possible. Point-to-point service is assumed for these analyses however it is acknowledged that this is not necessarily the most cost efficient method. Developing a routing model based on the objective of minimizing total logistics costs while maximizing service levels would more accurately reveal how the cargo airship could impact on the NWC's operations.

The findings from the CENU region raise the question of what cruising speed is ideal for the cargo airship. Although freight does not necessarily need to move more quickly, higher cruising speeds could increase the cost advantage of the cargo airship. Increasing the cruising speed of the cargo airship requires burning more fuel but it also allows for a greater number of revenue-generating operating cycles and a greater amount of activity over which fixed ownership costs can be spread. Research into the trade-offs between the cargo airship's cruising speed and profitability would provide greater insight into where the cargo airship is most competitive and how its advantages can be maximized.

It is assumed in this research that the operating characteristics and cost estimates provided by the cargo airship developer are accurate. The ultimate litmus test of the accuracy of these estimates is to build and fly a cargo airship. Short of this, an engineering feasibility study could reveal whether these operating cost estimates are indeed reliable.

Future research in this or other regions should also be conducted to determine what size of cargo airship is ideal for serving small, isolated communities. This relates to achieving service level objectives. There may be a conflict between minimizing freight transportation costs and achieving service level objectives that relate to selecting an optimally-sized cargo airship. A smaller cargo airship may provide the trip frequency desired by a shipper but a relatively larger cargo airship might provide the least cost alternative.

In the same vein, a variety of cargo airship designs are proposed by developers. Each of them might vary in certain ways that make some more suited to northern freight transportation than others, both in terms of their economics and their operating characteristics. More consultation with cargo airship developers to include a greater variety of cargo airship designs into the cost comparison analyses would provide more insight into cargo airships generally.

One of the key assumptions made in the costing analyses is that a large enough transportation market exists in isolated northern regions to support the operation of one cargo airship for 7,200 hours. Investigation into the total demand for cargo airship transportation service can be conducted with other freight shippers and in passenger transport markets.

The passenger transport market in particular would be a topic of interest for future research. A preliminary analysis of the potential demand for cargo airship transport service in the ESLW, NWON, and CENU regions inclusive of passenger travel is found in appendix B. The range of demand for a cargo airship with a 50t payload is between slightly more than one-third and 2.5 times the 7,200 total occupied hours assumed in the preceding analyses. Inclusion of passenger transport data would provide insight into the total market potential of heavy-lift cargo airships.

One of the major limitations of this research is that it is focused on one shipper. Accurate estimates of cargo airship demand require investigation into the freight transportation demand of other shippers and the competiveness of cargo airships for moving other types of cargo. Moreover, research on freight transportation flows in other regions and for potential future freight transportation demand completes the picture for the Canadian context. The numbers given above are for existing flows however it is expected that the availability of low-cost air transport would encourage entirely new human activity and transportation demand in these and other isolated regions.

Finally, investigation into the second-order impacts of reduced transportation costs on the case regions is necessary. Access to nutritious foods and economic opportunities in isolated regions is limited by high transportation costs. The employment of cargo airship technology to serve isolated regions could significantly alter food consumption patterns and these changes ultimately would potentially positively impact community health. The availability of low-cost freight transportation on the backhaul out of isolated communities presents an opportunity for economic development. Investigation into these topics is necessary to understand the full range of impacts of cargo airship technology.

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Appendix A – Innovation Literature Review

I Introduction

The following literature review summarizes the theoretical underpinnings of the research conducted in chapter three. It is guided by the following research questions:

RQ1: What is the innovation diffusion process?

RQ2: What are the stages of an innovation's development?

RQ3: Which stakeholders groups have the power to disrupt cargo airship development?

RQ4: What is the role of information in these processes?

Developing an understanding of the factors that affect the success of an innovation and its rate of adoption requires an investigation into diffusion of innovation (DOI) literature. This provides insight into the innovation and adopter characteristics that affect an innovation's success or rate of adoption, and the process by which adopters make adoption decisions. Moreover, DOI literature is supplemented by innovation development theory. Innovation development literature provides insight into the actions and decisions that affect the innovation's eventual success post-commercial launch. Transportation innovations present a unique circumstance because multiple stakeholders are typically involved in adoption-decisions. Literature on stakeholder management theory and stakeholder dynamics in innovation diffusion situations is presented to describe the decision environment for transportation innovations like the cargo airship.

II Innovation Characteristics

Table 57 on the following page summarizes the innovation characteristics that have been shown to influence rates of diffusion. Innovations are more rapidly diffused if adopters perceive that they provide a benefit, are easy to understand and use, are aligned with the adopters' beliefs and practices, provide readily observable results, and can be used on a trial basis (Rogers, 2003). A significant amount of research into innovation diffusion focuses on aspects of an innovation's relative advantage (Baldwin & Lin, 2002; Bunduchi, Weisshaar, & Smart, 2011; Smart, Bunduchi, & Gerst, 2010; Cooper & Kleinschmidt, 2000).

Table 57 - Innovation characteristics and their relationships with adoption rate. Source: (Rogers, 2003).

Characteristic	Definition	Relationship
Relative Advantage	The perceived net benefit of adopting an innovation based on economic, social, or psychological criteria.	Positive
Compatibility	The perceived alignment between an innovation and the adopting-unit's values and beliefs, previously adopted innovations, and needs.	Positive
Complexity	The perceived level of difficulty of understanding and using the innovation.	Negative
Trialability	The degree to which adopters may learn about an innovation through its use on a limited scale.	Positive
Observability	The ability of adopters to learn of consequences.	Positive

A common view is that innovations provide instrumental value (Garcia & Calantone, 2002). Adopters seek out innovations they perceive will produce desirable changes, or consequences, (Rogers, 2003; Agarwal & Prasad, 1997; Henderson & Clark, 1990) and reject or even resist innovations they perceive will produce negative consequences. Innovations vary in terms of the magnitude of their consequences as perceived by potential adopters (Henderson & Clark, 1990; Garcia & Calantone, 2002; Abernathy & Clark, 1985). In other words, innovations are perceived by potential adopters as increasingly desirable or undesirable owing to the consequences of their adoption and diffusion.

Rogers (2003) emphasizes that it is adopter perceptions of the above that influence an innovation's diffusion. Although an innovation may be objectively superior in technical performance, it may nonetheless fail to diffuse (Nelson, Peterhansl, & Bhaven, 2004). Adopters may not perceive the performance of the innovation as superior even though it may measurably be so. In addition, superior technical performance alone may be insufficient to ensure diffusion if the innovation is, for example, too difficult for them to understand or if the technical superiority is irrelevant to their needs. In summary, an innovation must appeal to adopters on many fronts and in the ways that are relevant to them. The benefits of an innovation must be readily apparent to them and easily obtained if the innovation is adopted.

III Adopters of Innovations – Individuals and Organizations

Table 58 – Adopter Categories. Source: (Rogers, 2003).

Category	Proportion	Description
Innovators	2.5%	Risk- and experience-seeking. Cope well with uncertainty. Relatively wealthy. Not an opinion leader for others within its social system.
Early Adopters	13.5%	Opinion leaders within the social system. Maintains opinion leadership by making successful innovation adoption decisions.
Early Majority	34%	Well-connected within the social system but not opinion leaders. Significantly longer adoption-decision period than earlier adopters.
Late Majority	34%	Skeptical of innovations. Adopt to avoid economic or social consequences. Relatively low wealth.
Laggards	16%	Suspicious of innovation. Not well-connected within the social system. Risk-averse due to lack of resources.

The innovation diffusion curve illustrated in figure 4 in chapter three takes its shape because individuals vary on their ability and willingness to adopt innovations, or innovativeness (Rogers, 2003). As shown in table 58, greater innovativeness is associated with greater wealth, education, number and diversity of communications linkages, and capacity to cope with uncertainty (Rogers, 2003). Individual-level personality characteristics act to moderate perceptions of an innovation's objective performance (Franke & Krems, 2013). For example, adopters are more likely to adopt an innovation if they are confident in their ability to use it (Ellen, Bearden, & Sharma, 1991).These factors are what causes the difference between the objective performance of an innovation and its performance as perceived by a potential adopter.

Organizations also vary on innovativeness. The availability of free resources (Gomez & Vargas, 2008), along with a flat and decentralized organizational structure, openness to receiving new information, and intra-firm professional variety all increase innovativeness (Rogers, 2003). Unlike individuals, however, the impetus driving a firm's need to innovate is a desire to enhance or create competitive advantage (Grawe, 2009). In addition, organizational innovativeness is moderated by previous competitive performance (Cantor, Corsi, & Grimm, 2008), the industry the organization competes in (Klevorick et al., 1995), the level of competition the firm faces (Frambach, 1993), and firm strategy (Patterson, Grimm, & Corsi, 2003). Implementation is more complex for organizations than for individuals (Rogers, 2003; Russell & Hoag, 2004; Thiesse et al., 2011). Each end-user makes an adoption decision once the innovation is introduced into the organization. End-user rejection leads to implementation failure.

In summary, there is no one common adopter, although they may fall into groups that make them more alike than not. Successful diffusion depends in part on an innovation's ability to appeal to different types of adopters.

IV Innovation-Decision Processes

Rogers' (2003) five stage innovation-decision process is summarized in table 59. The Technology Acceptance Model (Venkatesh & Davis, 2000), the Theory of Planned Behavior, and the Theory of Reasoned Action models (Madden, Ellen, & Ajzen, 1992) describe a similar process whereby an individual seeks or receives information about an innovation and makes a decision about whether or not to adopt it. Organizational adoption-decision models follow a similar pattern but incorporate group decision-making dynamics and are more formal that individual-level decision models (Rogers, 2003).

Table 59 – Five-stage innovation-decision process and outcomes. Source: (Rogers, 2003).

Innovation-Decision Stage	Outcome(s)
Knowledge	That the innovation exists, how it is used, and the principles behind its functioning.
Persuasion	The decision-maker forms either a positive or negative attitude towards the innovation based on an evaluation of its perceived characteristics.
Decision	The decision-maker either adopts the innovation or rejects it with or without trying it.
Implementation	The innovation is incorporated into the adopter's routines.
Confirmation	The decision-maker evaluates the actual performance of the innovation and either continues its use or abandons it. The innovation may be abandoned because of poor performance or because a more attractive innovation emerges.

The decision to adopt in either case is based on the decision-maker's perceived consequences of adoption. Although the consequences of an adoption decision may affect a wide range of individuals, adopters tend to weigh more heavily the consequences they experience directly in their decision (Patterson, Corsi, & Grimm, 2004). As mentioned earlier, innovations vary in the magnitude of their consequences. Adopters perceive greater uncertainty about an innovation they greater they perceive the severity of the innovation's consequences (Henderson & Clark, 1990; Garcia & Calantone, 2002; Abernathy & Clark, 1985). The amount of perceived uncertainty affects the criteria adopters use to evaluate an innovation. When perceived uncertainty is high, adopters are more concerned with whether or not an innovation will work and are consequently less responsive to appeals made about its potential benefits (Antioco & Kleignan, 2010; Schwartz, 1980). Greater perceived uncertainty causes adopters to hesitate in their decision-making, thus it impedes the diffusion of the innovation (Troshmi & Doolin, 2007).

Adoption-decisions are ultimately a process of uncertainty reduction (Rogers, 2003). Uncertainty is distinct from risk in that potential outcomes are unknown because information is lacking (Epstein, 1999). Uncertainty abounds in adoption-decisions because the consequences of adoption are only known after the fact (Vincenti, 1994), if at all. Uncertainty can be reduced, however, by information about the innovation and its consequences (Rogers, 2003). The greater the quality of the information from the perspective of the adopter, in terms of addressing their particular uncertainties, the more likely it is that the innovation will be adopted (Myers, 1977; Harborne, Hendry, & Brown, 2007). A critical role of an innovation's developer is to generate and communicate information about the innovation that demonstrates its performance (Rogers, 2003; Cooper, 1990). This information must be tailored to the adopter's needs in terms of its quantity, quality, format, and source (Rogers, 2003; Gomez & Vargas, 2008). Conversely, a lack of information will lead to an innovation's failure to diffuse.

V Impediments and Resistance to Innovation Adoption

Although most DOI research focuses on successful innovations, the reality is that most innovations fail to diffuse (Tzokas, Hultink, & Hart, 2004; Cooper, 1990; Ram & Sheth, 1989). The diffusion of an innovation may be impeded by innovation-related or contextual factors or adopters may resist the innovation's diffusion.

Innovation-related impediments include shortcomings in its performance (Egbue & Lang, 2012), for example with an emerging technology, as well as the performance of supporting or component technologies (Vincenti, 1994), and whether the innovation can substitute for an existing technology (Costa & Fernandes, 2012). In addition, a lack of supporting infrastructure and sources of supply (Farrell, Keith, & Corbett, 2003; Graham-Rowe et al., 2012), cost (Smart, Bunduchi, & Gerst, 2010), especially for innovations that are indivisible and depend on network returns (Wiegmans, Hekkert, & Langstraat, 2007), and a lack of a standard or dominant design (Troshani & Doolin, 2007; Baker, 1989) all act to impede the widespread diffusion of an innovation.

Impediments to diffusion may arise from the context in which the adoption-decision takes place. Organizational innovations in particular are subject to a number of potential impediments. These include managerial attitudes towards the innovation (Baldwin & Lin, 2002), workforce reactions (Baldwin & Lin, 2002), sunk capital in existing technologies (Farrell, Keith, & Corbett, 2003), and the use of inappropriate processes for evaluating innovations (Christiansen & Bower, 1996).

Impediments may also arise from the actions, or inactions, of third parties to the adopting firm. Government-related impediments are particularly influential because some innovations can only be adopted if government authorities have first created a permissive regulatory environment (Baldwin & Lin, 2002; Mulley et al., 2012). Moreover, government can be facilitative to innovation creation by investing in research and development. However, they may also withhold investment, thus leaving certain innovations unable to progress from their conceptual form.

Certain innovations attract resistance from adopters. Adopters may pass through the early stages of the innovation-decision process and choose to postpone their adoption-decision, reject the innovation, or actively oppose its diffusion (Ram & Sheth, 1989; Kleijnen, Lee, & Wetzels, 2009). These reactions are based on perceived risks associated with potential physical harm, financial losses, conflicts with social norms and existing lifestyle patterns (Ram & Sheth, 1989; Wiedmann et al., 2011; Graham-Rowe et al., 2012), and a loss of privacy (Swilly, 2010). The more severe the adopter perceives the risks or conflicts to be, the greater the severity of their resistance (Ram & Sheth, 1989). It is also possible for adopters to develop negative attitudes towards all innovations generally because they have experienced negative adoption consequences in the past (Rogers, 2003).

Resistive forces may also emerge from third party stakeholder groups. These stakeholder groups may have an interest in ensuring the continued use of an existing technology (Woodside, 1996) or an alternative technology, or they may object to the external consequences of the diffusion of an innovation. The successful diffusion of an innovation in these cases depends on the balance of power being in favour of the innovation's developer or adopter (Greenhalgh et al., 2004).

In summary, the diffusion of an innovation is not guaranteed. Innovation's face numerous impediments and may potentially encounter strong resistance. Innovation diffusion depends on overcoming impediments or preventing active resistance as much as it depends on the value of the innovation as perceived by potential adopters. The action, or inaction, of third parties to the adopter-developer relationship in particular is salient to the diffusion of transportation innovations. Managing stakeholder relationships becomes a success factor in an innovation's diffusion process.

VI Stakeholder Management in Innovation Development and Diffusion Processes

Certain innovation diffusion processes take place an in a stakeholder environment. Stakeholders are entities with an interest in the actions of another entity (Donaldson & Preston, 1995). Innovations that are increasingly disruptive, and consequently create increasing uncertainties for stakeholders, are subject to greater stakeholder action (Hall & Martin, 2005). In such circumstances, adopters of an innovation, defined as the end-user of the innovation, may not be able to make their adoption-decisions freely. The outcome of their decision may depend on the actions of the other stakeholders involved.

Stakeholder groups that can influence an innovation's progress include government, investors, political groups, customers, employees, trade associations, and suppliers (Donaldson & Preston, 1995; Choudrie & Papazafeiropoulou, 2003; Hart & Sharma, 2004; Byrne & Polonsky, 2001). Stakeholders vary in terms of their ability to influence innovation development or diffusion outcomes (Mitchell, Agle, and Wood, 1997). Stakeholder influence varies over time such that certain stakeholders groups are influential only at certain stages of an innovation's lifecycle (Hall & Martin, 2005). Additional complexity arises from the divergent interests of various stakeholder groups. Some might be motivated by economic consequences (Woodside, 1996) while others might be motivated by social or environmental consequences (Hart & Sharma, 2004).

Successful stakeholder management requires action that reduces the amount of uncertainty perceived by stakeholders about the innovation. This is accomplished by generating and communicating information about the innovation that addresses their uncertainties (Brown, 2003). Information that achieves this objective is generated through two-way stakeholder communication (Hart & Sharma, 2004) and by including stakeholders in the development process (Hillebrand & Biemans, 2004).

VII Innovation Development and Diffusion – A Complete Lifecycle

Table 60 - Innovation development and diffusion stages. Sources: [a]Rogers (2003); [b]Tzokas, Hultink, & Hart (2003); [c]Cooper (1990); [d]Baker (1989).

<table>
<tr><th>Generation and Diffusion Stages</th><th>Innovation Generation[a]</th><th>Stage-Gate NPD Process[b,c]</th><th>Technology Lifecycle[d]</th></tr>
<tr><td>Conceptual</td><td>• Problem recognition
• Basic and applied research</td><td>• Idea Generation
• Concept Development</td><td>• Pre-prototype</td></tr>
<tr><td>Developmental</td><td>• Development
• Commercialization</td><td>• Product Development
• Market Testing</td><td>• Emerging</td></tr>
<tr><td>Available</td><td rowspan="2">• Diffusion & adoption</td><td>• Market Launch</td><td>• Emerging
• Maturing</td></tr>
<tr><td>Viable</td><td>• Post-Launch Review</td><td>• Maturing
• Established
• Outmoded</td></tr>
</table>

Innovation development processes have received significant research attention (Hart & Baker, 1994), and there is a relationship between the management of an innovation's development and its successful diffusion. Three innovation development and lifecycle models are summarized in table 60. The stages of innovation development are sourced from Rogers (2003). This is supplemented by the stage-gate NPD process, a process whereby stages of innovation development activity are interspersed by evaluation stages about whether to continue or cancel the development project (Tzokas, Hultink, & Hart, 2003; Cooper, 1990). The technology lifecycle model describes how an innovation emerges, is adopted, and is eventually abandoned (Baker, 1989).

Two broad themes emerge from innovation development literature. The first is that the innovation progresses over time from an abstract concept to an adoptable and useable technology. The four development stage categories on the left-hand side of table 60 describe these stages. In the conceptual stage, the core concepts of the innovation are developed and tested virtually or in a laboratory setting. The developmental stage is when the concept transitions from the abstract into the useful. The hardware element of the innovation (Rogers, 2003), if it has one, is developed in this stage. So although an innovation changes in outward form throughout its lifecycle, the core concept of the innovation endures.

The second is that innovation development processes are as much about information generation and evaluation as they are about engineering or marketing activities. Developers of an innovation require resources from other decision-makers or stakeholders to continue development efforts (Tzokas, Hultink, & Hart, 2003). Whether investors or government regulators, stakeholders must expend resources to support an innovation's development (Byrne & Polonsky, 2001; Cooper, 1990) and require a compelling reason for doing so. The motivation to invest in an innovation's development, whether by providing financial resources or by creating permissive regulations, comes from information that provides evidence of the innovation's value.

One of the critical roles of the developer in the development process is to generate and communicate information to stakeholders that illustrates the innovation's performance in theory and later in practice (Tzokas, Hultink, & Hart, 2003). Information requirements vary at different stages of development in terms of quality and type. Progress from a conceptual stage to a developmental stage depends on the developer's ability to provide evidence of an innovation's potential financial performance while in latter stages they require evidence that the innovation will meet its technical performance expectations (Cooper, 1990). As development efforts continue, stakeholders require information that is increasingly accurate and concrete (Tzokas, Hultink, & Hart, 2003). Evaluations made later in the development cycle are based on whether or not the innovation is capable of meeting its technical performance expectations.

Another means of reducing the uncertainty of stakeholders whose support is necessary is to demonstrate that the risk of development failure has been minimized by following the stages of development. Skipping steps in the development process results in a higher likelihood that the innovation will fail to meet its performance expectations. Despite this, skipping development stages is a common error made by innovation developers (Cooper, 1990).

VIII Conclusion

Contrary to an objectivist perspective, an innovation will not necessarily be adopted because it is endowed with objectively superior performance. An innovation’s successful diffusion depends on it being perceived as beneficial by potential adopters, something that is distinct from its objective benefits. This perception of utility depends on the combination of the innovation’s and the adopter’s characteristics. While some innovations are perceived as beneficial, others are perceived as harmful and may give rise to adopter resistance.

In addition, innovations may fail to diffuse even though individuals or organizations wish to adopt them. Impediments to an innovation’s diffusion can arise from the characteristics of the innovation itself as well as the context in which the adoption-decision is made. The adoption-decisions made in multi-stakeholder contexts are especially complex. Adopters may not be free to make their adoption decisions because their decision to adopt may be impeded by the actions or decisions of other stakeholders.

Adopter and stakeholder resistance to an innovation, whether active or passive, arises mainly from uncertainty. Greater perceived uncertainty leads to more active resistance towards an innovation's diffusion, or at the very least a greater reluctance to adopt. Information about an innovation's consequences reduces uncertainty such that sufficient information can turn resistance or reluctance to adoption. Developers play a key role in managing adopter and stakeholder perceptions of an innovation in that they produce the information that reduces uncertainty.

Appendix B – Preliminary Assessment of Demand for Cargo Airship Combi Service

Total freight transportation data is available for the ESLW, and are summarized in table 61. The NWC's freight transport demand is 14.1% of the total reported for the region. In addition to the demand for freight transport, a total of 110,670 passenger trips are made per year.

Table 61 - Comparison between total freight movements and the quantity of freight transported by the shipper and total passenger trips for the ESLW region. Total freight quantities and the number of passenger trips made in the ESLW are sourced from the East Side Road Scoping and Justification Study (Buhr, Krahn, & Westdal, 2000).

ESLW Community	Total t	NWC t	Proportion	Pass.Trips
Bloodvein	2,928		0.0%	2,805
Berens River	4,148	257.8	6.2%	3,400
Poplar River	2,584	357.9	13.9%	4,845
Little Grand Rapids	1,471	441.9	30.1%	6,545
Pauingassi	667	214.9	32.2%	2,550
St. Theresa Point	6,460	1,071.8	16.6%	11,900
Wasagamack	3,145	506.1	16.1%	3,400
Garden Hill/Island Lake	9,265	756.4	8.2%	39,100
Red Sucker Lake	2,593	296.0	11.4%	6,375
God's Lake Narrows	4,080	747.5	18.3%	10,200
God's River	1,751	404.3	23.1%	6,800
Oxford House	4,675	1,118.5	23.9%	12,750
Total	43,767	6,173.1	14.1%	110,670

Total t: Freight transport quantities in metric tonnes (t) as reported by Buhr, Krahn, & Westdal (2000).
NWC t: The North West Company's reported freight quantities in t.
Prop.: The proportion of each community's freight quantity represented by NWC shipments.
Passenger Trips: Annual number of passenger trips from each community by air.

Table 62 summarizes the total transportation demand in the ESLW region with passenger trips converted to metric tonnes. This is based on the average weight per passenger seat of a 737 combination aircraft[13] (First Air, 2013). The NWC requires 123.5 cargo airship trips within the region for its freight re-supply operation. Inclusion of passenger transportation demand increases this to 458.8 cargo airship trips annually.

Table 62 - Combined annual passenger and NWC cargo transportation demand in ESLW communities.

Community	NWC t	Pass.(t)	Total t	CA Trips
Bloodvein		425.0	425.0	8.5
Berens River	257.8	515.2	773.0	15.5
Poplar River	357.9	734.1	1,092.0	21.8
Little Grand Rapids	441.9	991.7	1,433.6	28.7
Pauingassi	214.9	386.4	601.3	12.0
St. Theresa Point	1,071.8	1,803.0	2,874.8	57.5
Wasagamack	506.1	515.2	1,021.3	20.4
Garden Hill/Island Lake	756.4	5,924.3	6,680.7	133.6
Red Sucker Lake	296	965.9	1,261.9	25.2
God's Lake Narrows	747.5	1,545.5	2,293.0	45.9
God's River	404.3	1,030.3	1,434.6	28.7
Oxford House	1,118.5	1,931.8	3,050.3	61.0
Total	6,173.1	16,768.3	22,941.4	458.8

NWC t: The North West Company's freight transportation demand in metric tonnes by community.
Pass. t: Passenger trips expressed in metric tonnes.
CA Trips: The number of 50t cargo airship trips to each community annually.

The inclusion of the NWON and CENU freight and passenger transportation demand data into this analysis provides an estimate of how many cargo airships could be required to serve all three regions. This analysis is summarized in table 63 on the following page. Total freight and passenger transportation demand is estimated for the NWON and CENU by calculating the per capita rates for each in the ESLW and applying these rates to the population of the former two regions. There are two scenarios shown for each region to provide an upper and lower estimate for how many cargo airships are

[13] This aircraft was selected rather than smaller combination aircraft because it more closely approximates the characteristics of a heavy-lift aircraft. This analysis showed that each passenger is the equivalent of approximately 334 pounds or 0.152 MT.

needed to fulfill transportation demand. The “NWC” scenarios provide the lower bound because they assume the cargo airship will carry only the NWC’s freight and a proportion of passengers equal to the proportion of the region’s total freight demand accounted for by the NWC’s requirements[14]. The “All” scenarios assume all cargo and passenger movements occur by cargo airship, thus providing the estimated upper bound. The lower bound estimate shows that all three regions could be served by one cargo airship operating at approximately one-third of its total capability. The upper bound estimate, however, shows that almost three cargo airships would be required to fulfill total transportation demand. These estimates are exclusive of any time required to reposition the aircraft thus total cargo airship demand would likely be even higher.

Table 63 - Estimates for total cargo airship requirements in the ESLW, NWON, and CENU regions.

Region and Scenario	FRT T	PSGR T	Total T	Trips	OH / Year
ESLW - NWC	6,173.1	2,365.1	8,538.2	170.8	976.6
ESLW - All	43,767.0	16,768.3	60,535.3	1,210.7	6,760.8
NWON - NWC	4,510.1	1,467.5	5,977.6	119.6	657.8
NWON - All	27,157.4	10,404.7	37,562.1	751.2	4,112.2
CENU - NWC	3,303.0	1,427.2	4,730.2	94.6	979.4
CENU - All	26,410.8	10,118.7	36,529.5	730.6	7,662.9
Total - NWC	13,986.2	5,259.8	19,246.0	384.9	2,613.7
Total - Total	97,335.2	37,291.7	134,627.0	2,692.5	18,535.9

FRT T: Freight demand in T.
PSGR T: Passenger transportation demand in T.
Total T: Combined freight and passenger transportation demand.
Trips: The number of trips required using a 50T capacity cargo airship.
OH/Year: The number of cargo airship occupied hours required to fulfill total transportation demand.

[14] For example, if a region has a total freight demand of 100 MT and the NWC’s requirements are for 25 MT of re-supply, then the NWC scenario assumes 25% of all freight and passenger movements will occur by cargo airship.

Appendix C – Sample Transportation Cost Comparison

The following analysis is included to illustrate in a step-by-step fashion how the cost comparison analyses are conducted. This analysis compares the cost of a notional freight transportation system that uses modes 1 and 2 to an alternative system that replaces mode 2 with mode 3. The notional case region's freight transportation network is illustrated in figure 45.

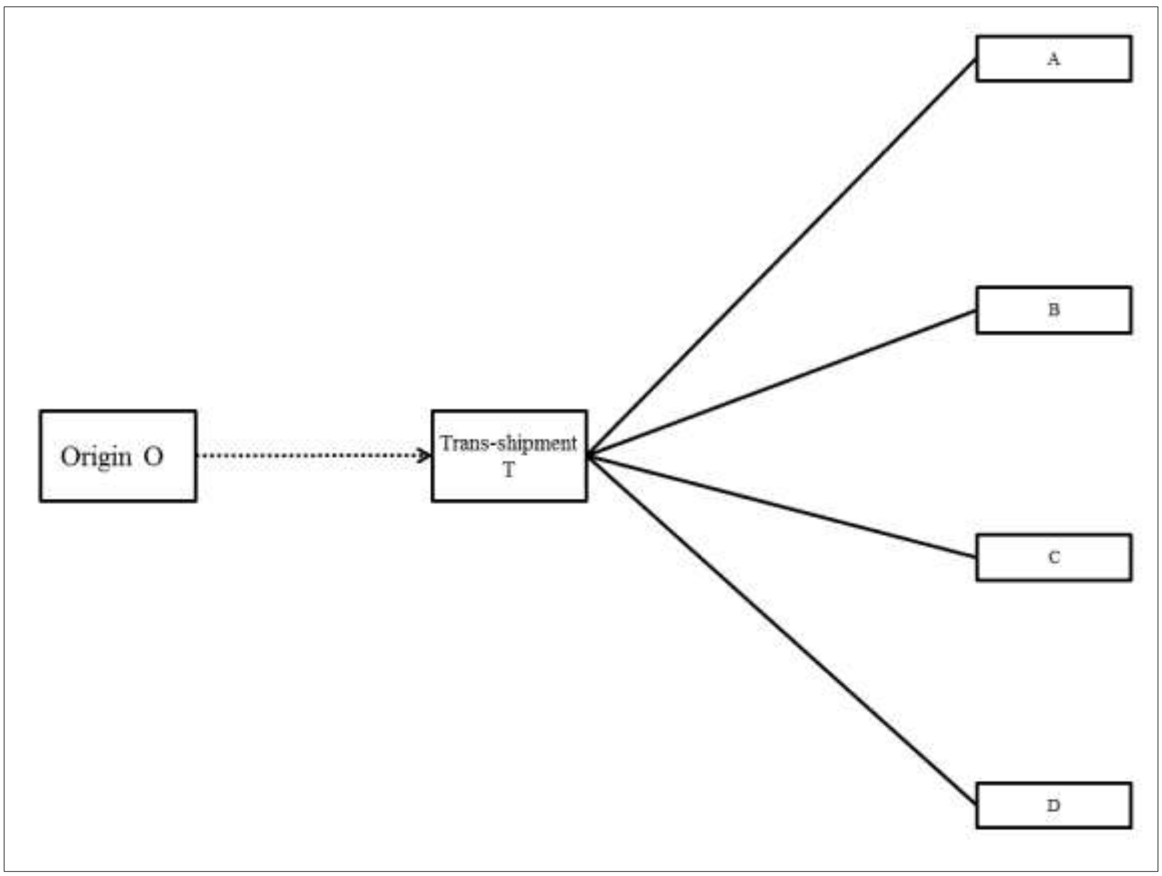

Figure 45 - Notional Transportation System. The dotted lines represent mode 1 flows and the solid lines represent mode 2 flows.

The transportation system for this notional region is composed of an origin O, a trans-shipment point T, and destinations A, B, C, and D. The dotted lines between O and T represent the flows for mode 1 and the solid lines represent the flows for mode 2. The notional data describing these flows are presented in table 64.

Table 64 - Data describing the notional freight flows - O-D pairs, mode, distance, quantity (t), and $/t.

Origin	Destination	Mode	Distance (km)	Quantity (t)	$/t
T	A	1	100	50	$30
T	B	1	150	75	$55
T	C	1	50	125	$40
T	D	1	75	100	$20
O	T	2	250	350	$5

Step 1: Calculate Baseline System Costs

The baseline system costs are the sum of the cost of each freight flow. These costs and the total baseline cost are calculated in table 65.

Table 65 – Notional baseline system cost calculation.

Origin	Destination	Mode	$/t	Quantity (t)	Cost ($)
T	A	1	$30	50	$1,500
T	B	1	$55	75	$4,125
T	C	1	$40	125	$5,000
T	D	1	$20	100	$2,000
O	T	2	$5	350	$1,750
				Total	$14,375

Step 2: Calculate Mode 3 Annual Trips

Assume that mode 3 is used to replace mode 2 only. The number of round-trips from the trans-shipment point to each community is based on each community's level of demand and the payload capacity of mode 3 vehicles. The calculation for the number of mode 3 trips required each year to each community based on a 50t payload capacity is presented in table 66. In total, mode 3 is needed for 7 trips annually.

Table 66 – Calculation for the number of mode 3 round-trips to each community assuming a 50t payload capacity.

Origin	Destination	Quantity (t)	Formula	Trips/Year
T	A	50	$50t \div 50t$	1
T	B	75	$75t \div 50t$	1.5
T	C	125	$125t \div 50t$	2.5
T	D	100	$100t \div 50t$	2

Step 3: Calculation of Block Hour Requirements

Trip block hour requirements to each destination are based on round-trip distances and the speed and operating characteristics of the mode 3 vehicle. Assume that the mode 3 vehicle exhibits the same characteristics as the cargo airship used in the preceding analyses. Its requirements in terms of block hours per trip and per year are calculated in table 67.

Table 67 – Calculation of mode 3 round-trip block hours (BH) per trip.

O	D	km	Formula	BH/Trip	Trips	BH/Year
T	A	100	$2\left[\left(\frac{(100 - 41.7)}{125}\right)+\left(\frac{2}{3}\right)\right]$	2.3	1	2.3
T	B	150	$2\left[\left(\frac{(150 - 41.7)}{125}\right)+\left(\frac{2}{3}\right)\right]$	3.1	1.5	4.7
T	C	50	$2\left[\left(\frac{(50 - 41.7)}{125}\right)+\left(\frac{2}{3}\right)\right]$	1.5	2.5	3.8
T	D	75	$2\left[\left(\frac{(75 - 41.7)}{125}\right)+\left(\frac{2}{3}\right)\right]$	1.9	2	3.8

O: Freight origin.
D: Freight destination.
Km: Distance in kilometers between origin and destination.
BH/Trip: Block hour requirements per trip between each O-D pair.
Trips: Annual cargo airship trips needed between each O-D pair.
BH/Year: Annual block hour requirements between each O-D pair.

Step 4: Calculation of Occupied Hour Requirements

Although the formula for calculating occupied hours differs slightly from the formula for calculating block hours, the underlying process is the same for the two. Occupied hours include in-flight time plus freight loading and unloading time. The calculations for trip and annual occupied hours are presented in table 68 on the following page.

Table 68 – Calculation of mode 3 round-trip block hours (OH) per trip.

O	D	km	Formula	OH/Trip	Trips	OH/Year
T	A	100	$2.3+\left(\frac{8}{6}\right)$	3.6	1	3.6
T	B	150	$3.1+\left(\frac{8}{6}\right)$	4.4	1.5	6.7
T	C	50	$1.5+\left(\frac{8}{6}\right)$	2.8	2.5	7.1
T	D	75	$1.9+\left(\frac{8}{6}\right)$	3.2	2	6.5

Step 5: Calculation of Mode 3 Costs

Assume the mode 3 vehicle costs $1,000 per block hour and $1,500 per occupied hour. Note that these are notional costs and do not indicate the output from the cargo airship operating cost model. The total cost of the mode 3 portion of the freight transportation system is calculated in table 69.

Table 69 – Calculation of mode 3 costs.

O	D	BH/Year	OH/Year	$/BH	$/OH	ABH $	AOH $	Total $
T	A	2.3	3.6	$1,000	$1,500	$2,300	$5,400	$7,700
T	B	4.7	6.7	$1,000	$1,500	$4,700	$10,050	$14,750
T	C	3.8	7.1	$1,000	$1,500	$3,800	$10,650	$14,450
T	D	3.8	6.5	$1,000	$1,500	$3,800	$9,750	$13,550
							Total	$50,450

O: Freight origin.
D: Freight destination.
BH/Year: Annual cargo airship block hour requirements.
OH/Year: Annual cargo airship occupied hour requirements.
$/BH: Cost, in dollars, per cargo airship block hour.
$/OH: Cost, in dollars, per cargo airship occupied hour.
ABH $: Annual cargo airship block hour costs.
AOH $: Annual cargo airship occupied hour costs.
Total $: The sum of the annual cargo airship block hour and occupied hour costs.

Step 5: Calculation of Cost Difference Between Alternatives

The final step is to calculate the net change in costs between the baseline system and the mode 3 system. This requires calculation of the cost difference for each community and summing the difference to determine the impact at the regional level. Note that each community pays a proportional amount of the mode 1 costs to the trans-shipment point based on its level of demand in metric tonnes. Also, mode 1 costs do not change between alternatives. These calculations are presented in table 70.

Table 70 – Calculation of cost differential between baseline and alternative notional transportation systems.

Dest.	M1 $	M2 $	M3 $	Base.	Alt.	*D*
A	$250	$1,500	$7,700	$1,750	$7,950	354.3%
B	$375	$4,125	$14,750	$4,500	$15,125	236.1%
C	$625	$5,000	$14,450	$5,625	$15,075	168.0%
D	$500	$2,000	$13,550	$2,500	$14,050	462.0%
Total				$14,375	$52,200	263.13%

Dest.: Freight destination.
M1 $: Annual costs of mode 1 between the origin and the trans-shipment point allocated to each respective destination.
M2 $: Annual costs of mode 2 the trans-shipment point and each respective destination.
M3 $: Annual costs of mode 3 the trans-shipment point and each respective destination.
Base.: Total annual baseline freight transportation costs. This is the sum of mode 1 and mode 2 costs for each destination.
Alt.: Total annual baseline freight transportation costs. This is the sum of mode 1 and mode 3 costs for each destination.
D: The proportional difference in annual costs between the alternative system and the baseline system expressed as a percentage.

The results in table 70 reveal that the alternative freight transportation system would be approximately 260% more costly than the baseline system. Community-level cost differences range from a low of 168% in community C to a high of 462% in community D.