Economics of Transport Airships for Food Distribution to Isolated Communities in Northern Manitoba and Ontario, Canada[1]

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INTRODUCTION

About 70 percent Canada's landmass lacks access to all-season road infrastructure. As a result, northern Canada must depend on transportation systems that are high-cost, unreliable, and with service levels that vary seasonally. The lack of low-cost, reliable freight transport service year-round imposes myriad negative impacts on the residents of these regions. For example, the cost of food in the remote communities is 2.5 to 3 times higher than the cost of food in the urban areas of Canada. Airships have been advanced as a potential solution to the high cost of transporting food and the general food insecurity of aboriginal communities in northern Canada (Council of Canadian Academies, 2014).

This paper assesses the potential for a transport airship to reduce the costs of food transportation to isolated communities in northern Manitoba and northwestern Ontario. The analysis is based on the operations of the North West Company's (NWC) grocery distribution system. The logistics costs for a proposed 50-tonne lift transport airship are compared to the costs of using ice road trucking and small airplanes to deliver food and general merchandise

The analysis begins with a description of the study region and the NWC shipping data. Subsequently, a brief background on the food retailer (NWC) is presented with data that describes current freight movements and associated costs. The third section presents the results based the North West Company's freight shipments versus the cost for a transport airship that was developed based on estimates provided by the developer and expert opinion.

STUDY AREA DESCRIPTION

The NWC was founded in the 17th century to compete with the Hudson's Bay Company in the Canadian fur trade (Keith, 2001). The NWC has evolved into a food and general merchandise

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[1] This paper has been prepared for presentation at the 10th Biennial International Airship Convention & Exhibition in conjunction with Aero Friedrichshafen from 16th to 18th April 2015 in Friedrichshafen, Germany

retailer that specializes in serving remote communities in northern Canada, Alaska, and island communities in the Caribbean and Guam (The North West Company, 2013). The company has achieved average annual revenues of $1.2 billion over the eight year period[2]. 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. 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. 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.

The Dataset

In co-operation with the University of Manitoba, the NWC provided freight transportation data for their entire network of stores across Canada for the period April 2010 – March 2011. The dataset 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. This information 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 is that this dataset may not describe all 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 shipments in terms of 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[3].

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[2] All values in this report are quoted in Canadian dollars.

[3] 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. Transport airship freight rates would likely be subsidized to the same degree as existing modes of transport making comparison unnecessary.

This dataset does, however, describe actual freight flows and actual transportation costs in regions that have received very little research attention previously (Adaman, 2013).

Selection of Cases

Figure 1 presents a map of the case study regions. The formulation of case regions is based on a set of selection criteria meant to ensure cross-case comparison. 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.

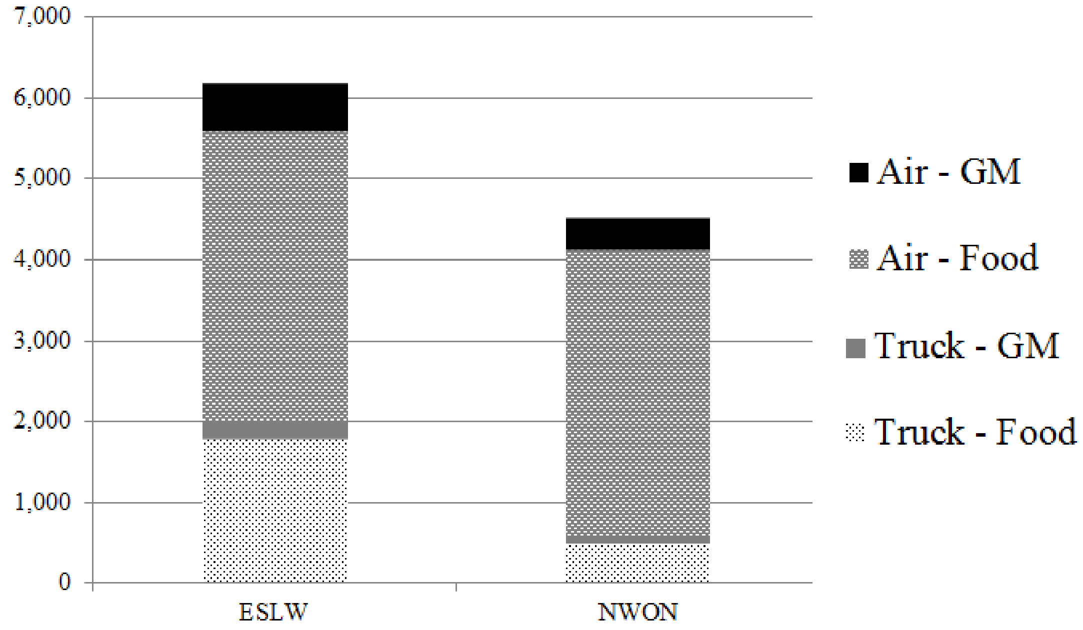
Figure 1 - Map of ESLW and NWON regions in Canada.

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

The first two criteria ensure a sufficient amount of transportation activity in each region. The third criterion is included in order to enhance the generalizability of the findings from these analyses. Two regions that meet these criteria are: The east-side of Lake Winnipeg (ESLW) in Manitoba and northwestern Ontario (NWON). Summary statistics shown in Figure 2 describe how each region differs in terms of geographic size, the number of communities and population, average air and ice road transport distances, and freight quantities.

Figure 2 - Summary Statistics for The North West Company Case Study Regions.

Region	km^2	Comm.	Pop.	Ice Roads	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



km^2: Land area of region in square kilometers.
Comm.: Number of communities in each region.
Pop.: Population of each region.
Ice Road: Average ice road kilometers, weighted by total ice road trucking MTK.
Air: Average air kilometers, weighted by total air transport MTK.
Air/ST: Modal split between air and surface transport in.
t: Total quantity of freight shipped to the region’s stores in metric tonnes.
T/C: Total freight quantity per capita.

These regions vary significantly in terms of land area, population density and modal split. Population density for the ESLW is 0.33 while the NWON is only 0.07 persons per square-kilometer. On a per capita basis, the ESLW received 0.49t freight and the NWON received 0.55t. A lower population density means greater distances must be overcome for freight re-supply. This is reflected in the average ice road distances in the NWON that are a third greater than the ESLW. Although the NWON has more kilometres of ice roads, these communities are more dependent on air transport than the ESLW communities (87% for NWON versus 68% for ESLW).

TRANSPORT AIRSHIP OPERATING COST MODEL

Several transport airship developers were contacted to provide operating cost data, but only one provided useful information for calculating transport airship trip costs. The transport airship is a rigid design in its early stages of development. Consequently, the operating cost model should be viewed as a best available estimate rather than actual transport airship operating costs. Further development and prototype testing will reveal the accuracy of these estimates.

The received cost data have been modified for this research to provide a more conservative estimate of the transport airship's performance. First, the cruising speed was reduced to approximate the speeds achieved by large rigid airships of the Zeppelin era. The helium leakage rate was increased to 5% per year. The length of the lease term for the transport airship and its hangar were decreased to 12 years and 25 years respectively[4]. Some of the staffing requirements were 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 transport airship used in a for-profit enterprise would require.

Because the shipper requested all dollar amounts remain confidential, the operating costs of the transport airship in dollar amounts must also remain confidential. Table 1 describes the general operating characteristics of the transport airship. The cruising speed of the transport airship is 125 km/h and it has a useful payload capacity of 50 metric tonnes (MT). The vehicle

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[4] A 12 year lease term is the maximum offered by aircraft financing.

utilization is equivalent to operating 24 hours per day for 300 days per year (7,200 operating hours). 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[5]. Details of the costing assumptions are contained in Appendix 1.

Table 1 – Transport airship general operating characteristics and finance terms.

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

The transport airship's operating costs are outlined in Table 2. Fuel consumption and maintenance requirements are variable cost drivers that accrue with each block hour. Fixed costs comprise 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 that the same regulations would apply to transport 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 pilot numbers to form a unitized flight crew. Ground crew staffing requirements are based on the assumptions that four ground crew working hours are required for every hour of transport airship operating time and that each ground crew member can work 2,000 hours per year.

Freight rates are set using a cost plus pricing model that includes a return on investment for the transport airship operator. 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 profit margin of 35% is used.

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[5] This number of hours may sound high to airplane operators, but it is necessary to note a couple of technical points. First, the airship is slower, and it burns even less fuel if it goes slower, still. The airship remains more time in the air for the same volume of traffic as an airplane. An airship is safer in the air, than on the ground, so it is better to keep them operating as much as possible.

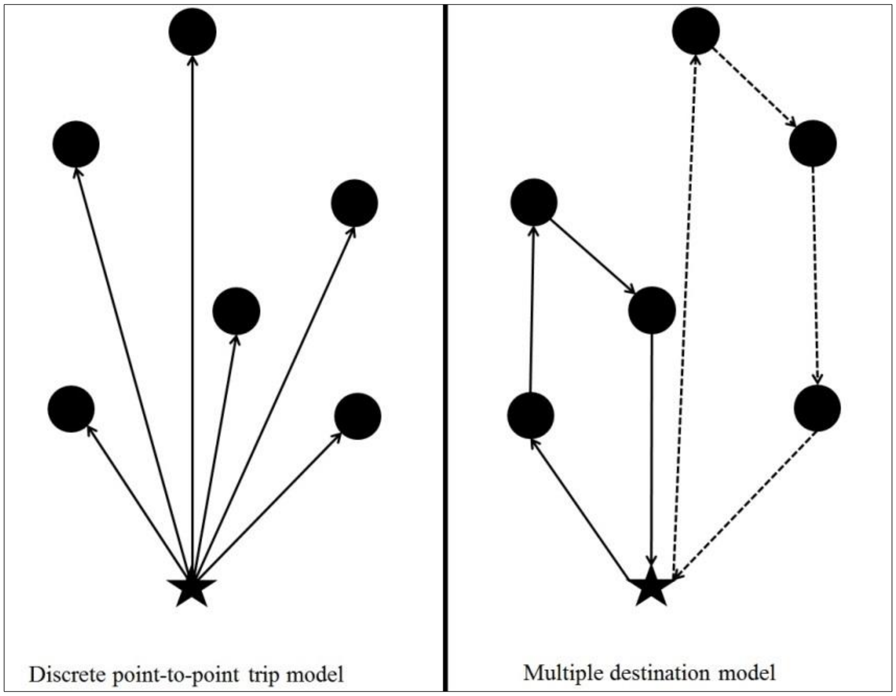
Table 2 - Transport airship operating cost drivers.

Variable Operating Costs	
Fuel Consumption Rate (Per Hour)	900 Liters
Maintenance Costs Rate	Per Block Hour
Fixed Operating Costs	
Transport Airship Lease Terms	
Lease Period	12 Years
Residual Value	30%
Effective Monthly Interest	0.7974%
Hangar Mortgage & Depreciation	
Amortization Period	25 Years
Effective Monthly Interest	0.4074%
Depreciation Schedule	Straight-line, 20 years, zero residual value
Insurance	
Annual Hull Insurance Cost	10% of airship purchase price
Annual P&L Insurance	5% of 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%

Transportation System Modelling

Figure 3 illustrates the two ways in which transport airship trips can be modeled. The simplest from an analytical perspective is point-to-point whereby the transport airship departs from an origin carrying a full load, flies directly to a store destination, and returns to the origin empty. This scheme does not make a routing choice based on cost, travel time, or trip frequency optimization. The alternative is to model chained trips ("milk runs"). In this case, the transport airship departs from an origin carrying a full load and delivers less-than-full loads to multiple destinations. The transport airship flies a circuit within each region and eventually returns to the origin empty.

Figure 3 – Illustration of trip modelling alternatives.



Modelling the transport 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. The weakness of the multiple destination model is the level of complexity involved in developing the algorithm that represents the underlying transportation system and service level objectives (García et al., 2013; Bonomo et al., 2012; Federgruen & van Ryzin, 1997). Indeed, the amount of computational work required to solve increasingly complex routing problems grows exponentially (Laporte, 2010).

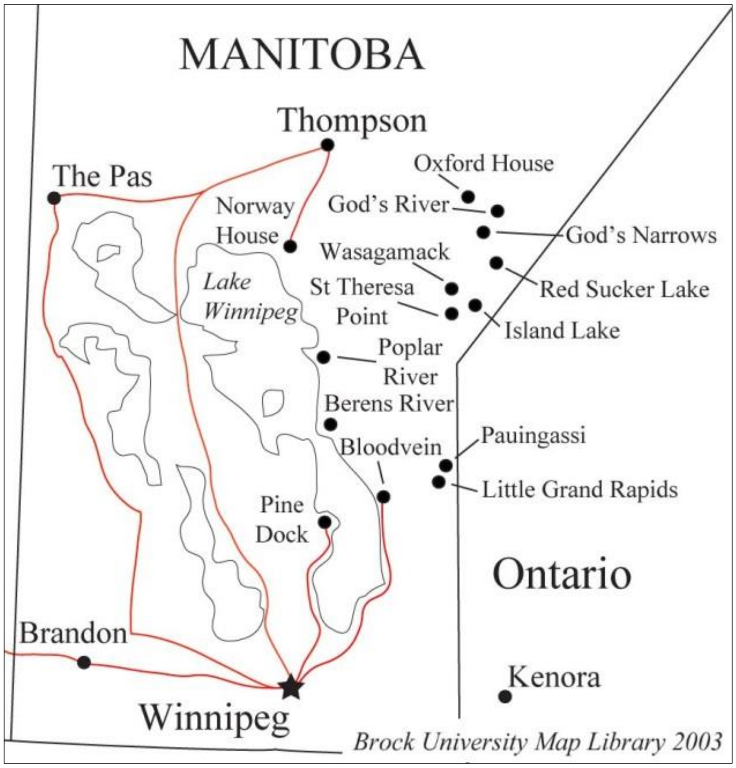
Chained trips could be modelled by arbitrarily clustering communities together based on geographic proximity. This may provide a routing solution that is lower-cost than point-to-point service but could also produce a solution that is higher-cost than a routing option based on optimization schemes because 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 transport airship's relative cost performance. A worst case scenario may be more appropriate given the stage of development of the transport airship under analysis.

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 return trip cost for full loads one way. Trip costs for partial loads are assigned to the NWC based on the proportion of the transport 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 transport 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 recognition that the total freight transportation demand is 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.

BASE CASE FOR THE EAST SIDE OF LAKE WINNIPEG (ESLW)

The ESLW 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. A map of the region is illustrated in Figure 4. 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 solid lines on the map. All goods are sourced at Winnipeg. Some goods are taken by air directly from Winnipeg, but more often air freight is trucked first to Thompson or to Pine Dock for transshipment to airplanes, in order to minimize costs. The ice roads are not illustrated on this map, but they are built to connect the remote communities to Norway House and Bloodvein.

Figure 4 - Map of the ESLW region and NWC communities.



Brock University Map Library 2003

Estimates suggest that ice road trucking accounts for approximately 70% of total freight transportation movements into the region (Buhr, Krahn, & Westdal, 2000). The ice 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 ice road network lies in the ESLW region. The Province of Manitoba has initiated a plan to construct an all-season road network at a cost of $2.7 billion to serve this area[6], but it is expected to take 30 years to complete. In the meantime, the region remains reliant on ice road trucking and air transport for its freight transportation needs.

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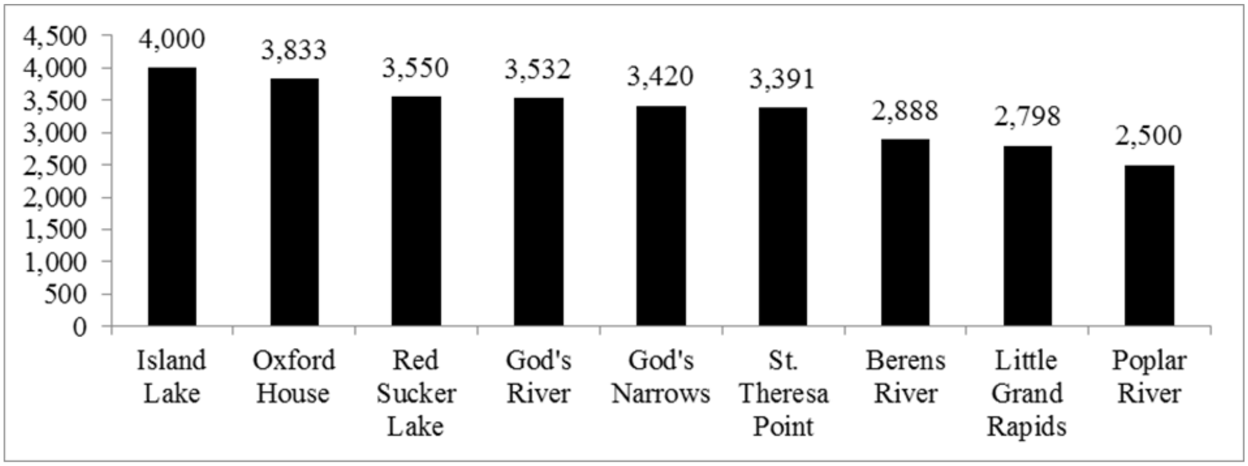
[6] This works out to be approximately $3 million per kilometer for the 878 kilometre gravel road network. This estimate does not consider annual maintenance or snow clearing costs (East Side Road Authority, 2011).

Air transport infrastructure in the region consists of gravel airstrips (Buhr, Krahn, & Westdal, 2000). Figure 5 presents 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. The region is served by 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. The NWC's data indicate that these aircraft are used year-round to re-supply their stores in the region.

Figure 5 – ESLW community gravel airstrips, length in feet.



Source: Manitoba Infrastructure and Transportation (2013).

Table 3 summarizes the freight shipped to the 11 stores in the ESLW, by means of transport. In total, 6,173.1t of freight was shipped to the 11 stores.

Table 3 – 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

In contrast to Buhr, Krahn, & Westdal (2000) who the estimate that 70 percent of freight to the remote communities is delivered by ice road, the share of NWC shipments by ice roads versus air transport is almost reversed. Even in the case of general merchandise (GM), which is less perishable, 75 percent of the shipments are delivered by airplanes.

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%).

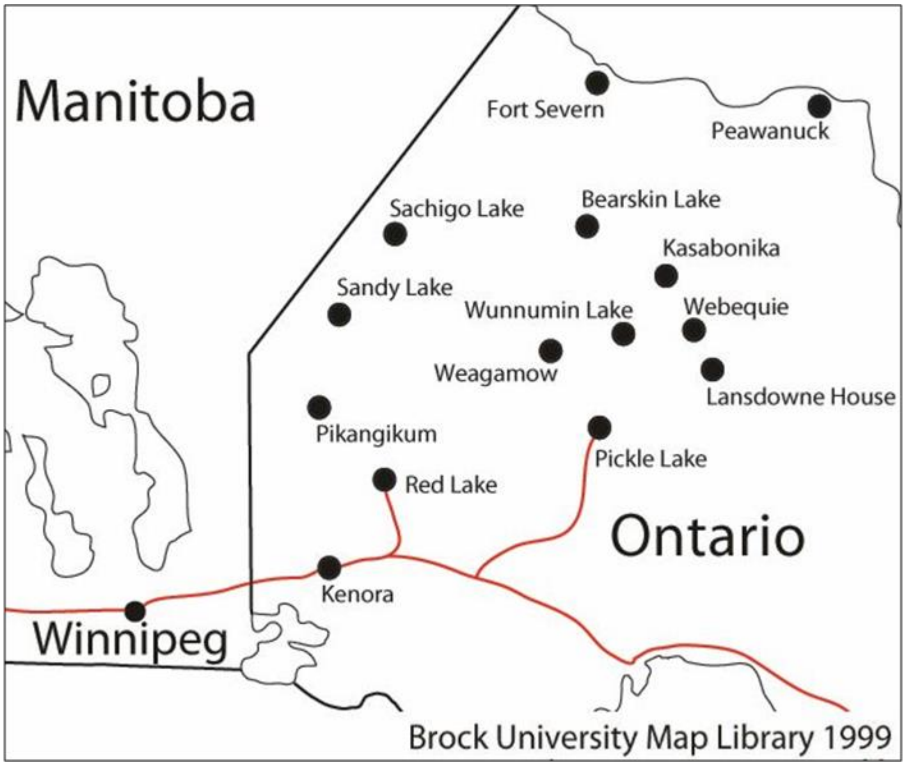
The split between freight-types is on average 87.2% food and 12.8% GM. At the upper end of the range is the Little Grand Rapids store; 95.1% of the freight this store receives is food. At the low end of the range is the Red Sucker Lake store at 78.1%. In terms of quantities, the Oxford House store receives 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).

The average quantity of freight received by these 11 stores is 561.2t, with a maximum of 1,118.5t at Oxford House and a minimum of 214.9t at Pauingassi. 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.

BASE CASE FOR THE NORTHWEST ONTARIO (NWON) CASE

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. A map of the NWON is illustrated in Figure 6. 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. Its features and obstacles include muskeg, numerous lakes, river crossings and dense forests.

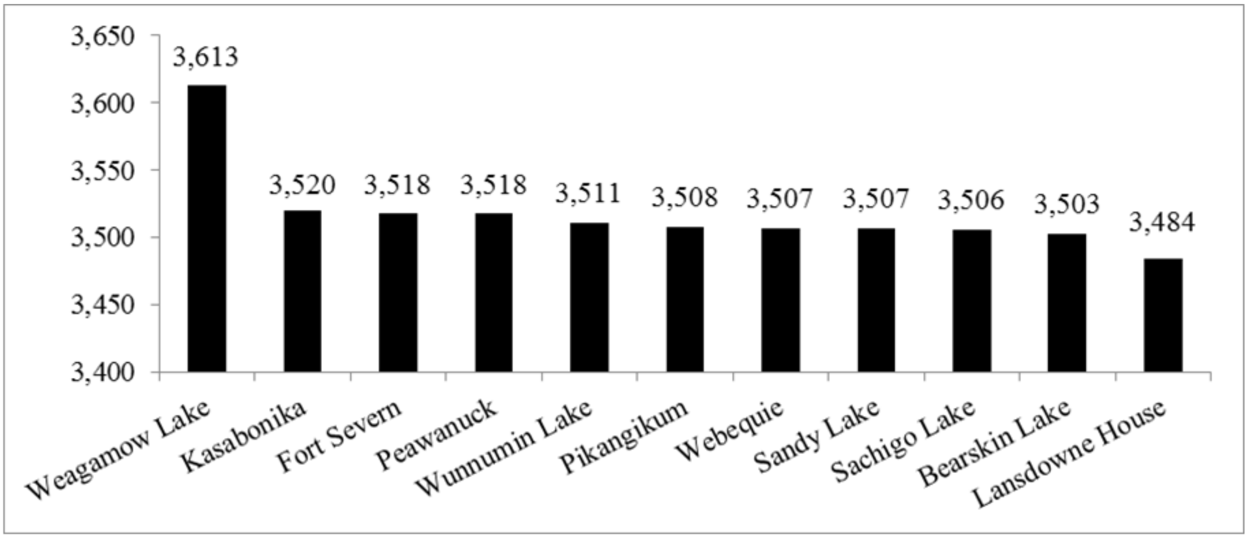
Figure 6 - Map of the NWON region and NWC communities.



Brock University Map Library 1999

The NWC operates stores in 11 remote communities of the NWON region. All the freight is originated and trucked from Winnipeg. Air shipments are trans-loaded from trucks to airplanes at Red Lake and Pickle Lake. Each of the 11 locations possesses a community airstrip. The lengths of these airstrips are presented in Figure 7. 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 7 – NWON Community airstrip length in feet.



Sources: Nav Canada (2013), Airplane Manager (2013)

Table 4 summarizes the freight demand by type and by the mode of transport used for delivery for each of the 11 stores.

Table 41 – 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

A number of the stores rely exclusively on air transport for re-supply despite being located in communities that are connected to the province's ice road network. It is unclear why no records exist of shipments via truck over ice roads to Webequie, Kasabonika, Sachigo Lake, Bearskin Lake, and Peawanuck. The lack of ice road trucking data could be because the roads are of poor quality and therefore impassable. Indeed, the poor condition of the ice road network in the NWON has been noted by shippers in the region (Pokrupa, 2007). In comparison with the ESLW, relatively little is spent per kilometer in the NWON on ice road construction. The Province of Ontario constructs more than 3,000 KM of ice roads at a cost of $4.5 million each year (Queen's Printer for Ontario, 2013). Neither the Province of Ontario, nor the federal government have taken any action to construct all-season road infrastructure.

For the stores that use both modes of transportation, the mean modal split is 19.2% ice road trucking and 80.8% air transport. Only six of the stores use ice-road trucking. Of those, Sandy Lake received the most freight by ice road (204t) and Wunnumin Lake the least (32.9t). Fort Severn receives the greatest proportion of its freight by ice 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 ice 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.

TRANSPORT AIRSHIP LOGISTICAL ALTERNATIVES: SUMMARY OF RESULTS

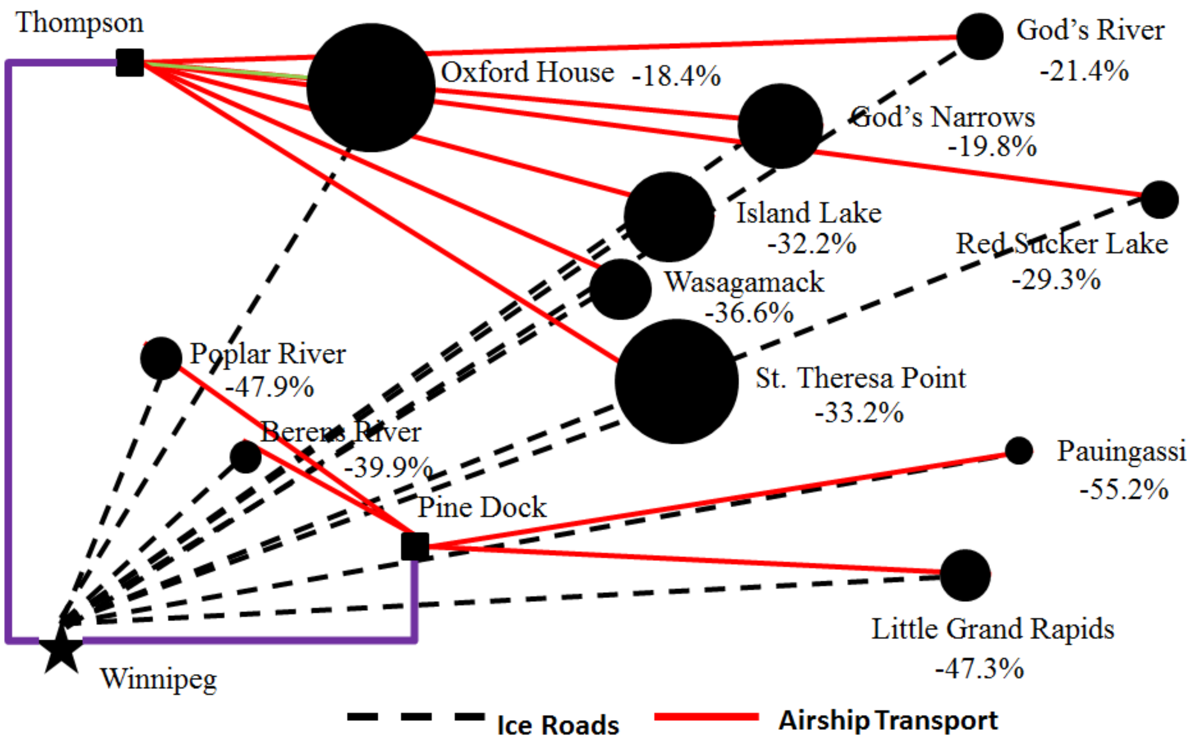
Two transport airship alternatives are tested in the ESLW and NWON cases. The first alternative involves replacing traditional air freight flows with a transport airship while keeping ice road trucking flows fixed. This alternative replaces only the cost vectors associated with using traditional aircraft with those associated with using transport airships. The second alternative assumes that both airplane and ice road shipments are delivered by transport airship.

ESLW Results

ESLW alternative 1 (transport airship replaces airplanes, ice road trucking flows remain fixed) requires a total of 83.6 transport airship trips and 0.96 million transport airship metric tonne-kilometre (MTK). In terms of utilization, the transport airship is required for a total of 363 block hours (BH) and 471.8 occupied hours (OH) per year.

Results for the cost comparison conducted for ESLW alternative 1 are described in Figure 8. To assist readers who are unfamiliar with this region, the communities are represented by circles that reflect their relative sizes. The ice road shipments are illustrated as dashed lines and the airship movements from Thompson and Pine Dock are represented as solid lines. The weighted average impact of the transport 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.

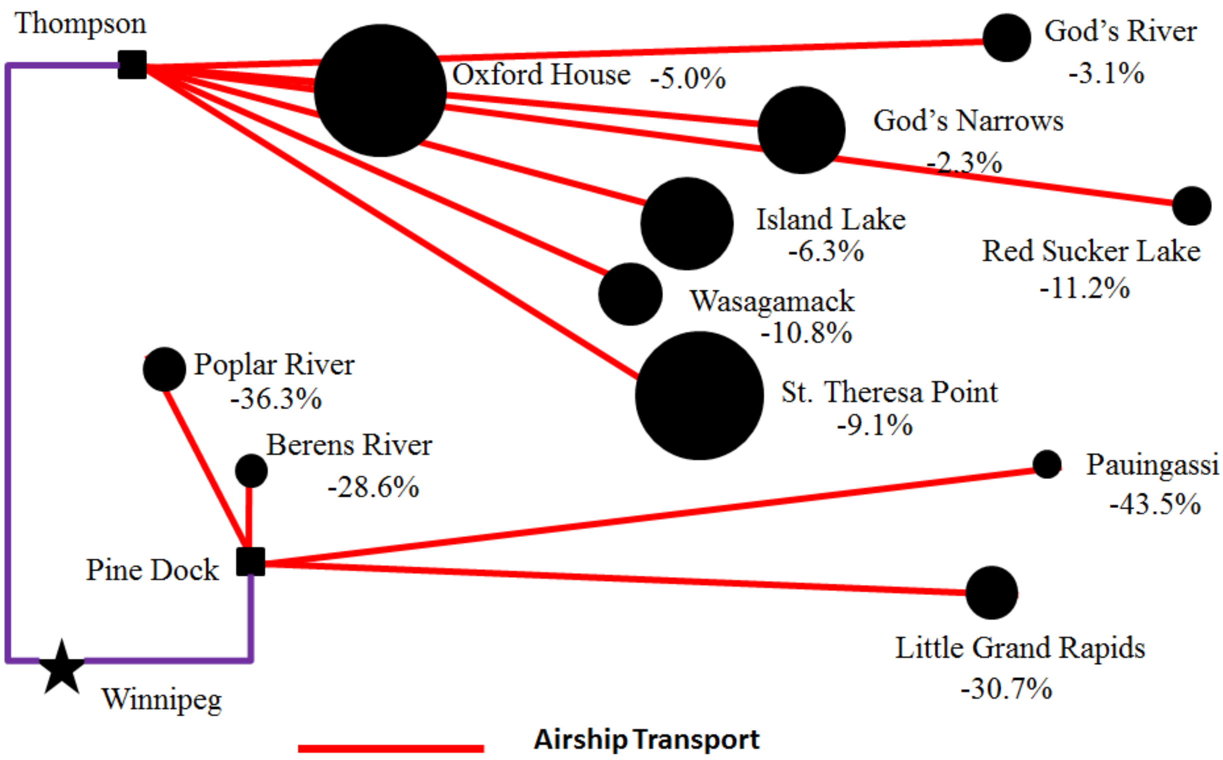
Figure 8 – Transport Airship Alternative 1 for ESLW Region – With Ice Roads



Scenario 2 assumes that ice road trucking is no longer used and all freight is shipped via transport airship. The transport airship freight flows for this alternative are described in Figure 9. All 6,173.1t of freight is carried to the ESLW communities from the trans-shipment points at Thompson and Pine Dock. This calls for a total of 1.4 million transport airship MTK, 539.7 BH, 700.4 OH and over 539.7 trips annually. Nearly half of the transport airship utilization is accounted for by the freight flows to Oxford House, St. Theresa Point, and Island Lake. The four communities served from Pine Dock together account for fewer transport airship operating and block hours than that required to serve Island Lake.

Shifting all the freight from ice roads and airplanes to the airship is better than the current base case, but generates less cost savings than if ice roads are still used. Of course, in interpreting of this result it has to be borne in mind that the shipper is only paying for the costs of trucking, not the construction and maintenance of the ice roads.

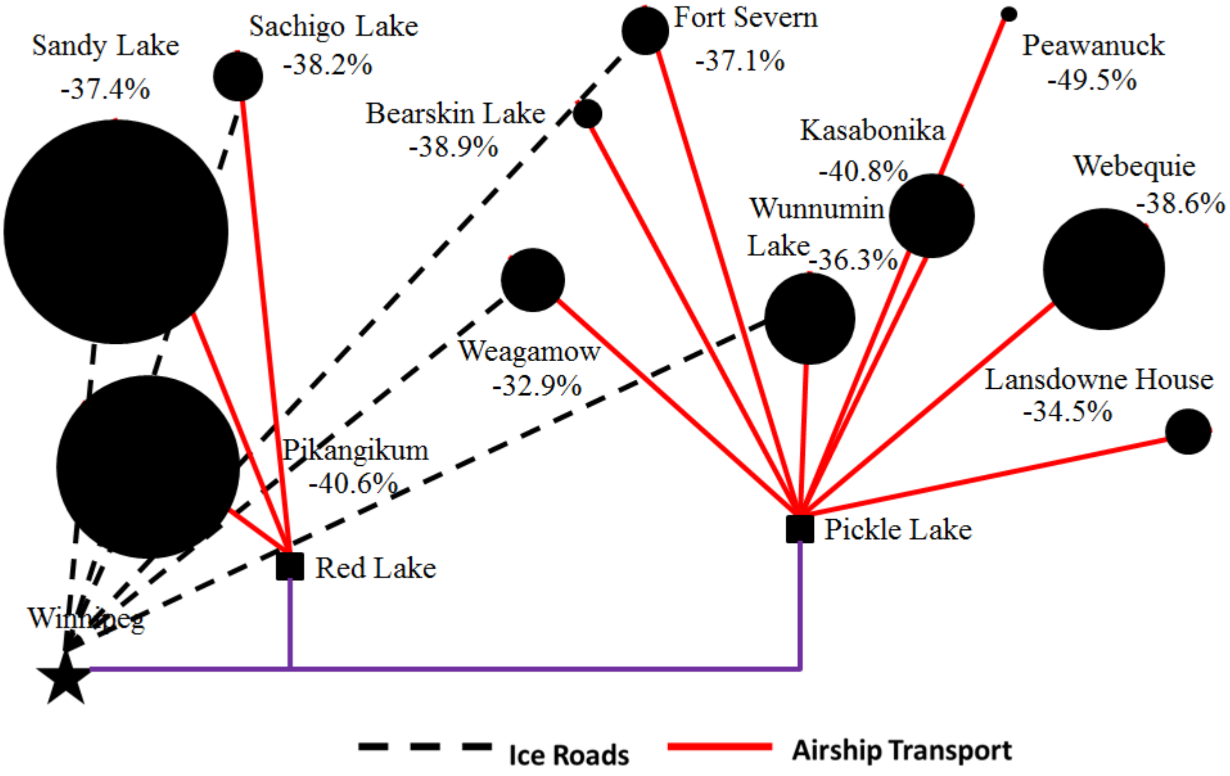
Figure 9 – Transport Airship Alternative 2 for ESLW Region – No Ice Roads



NWON Results

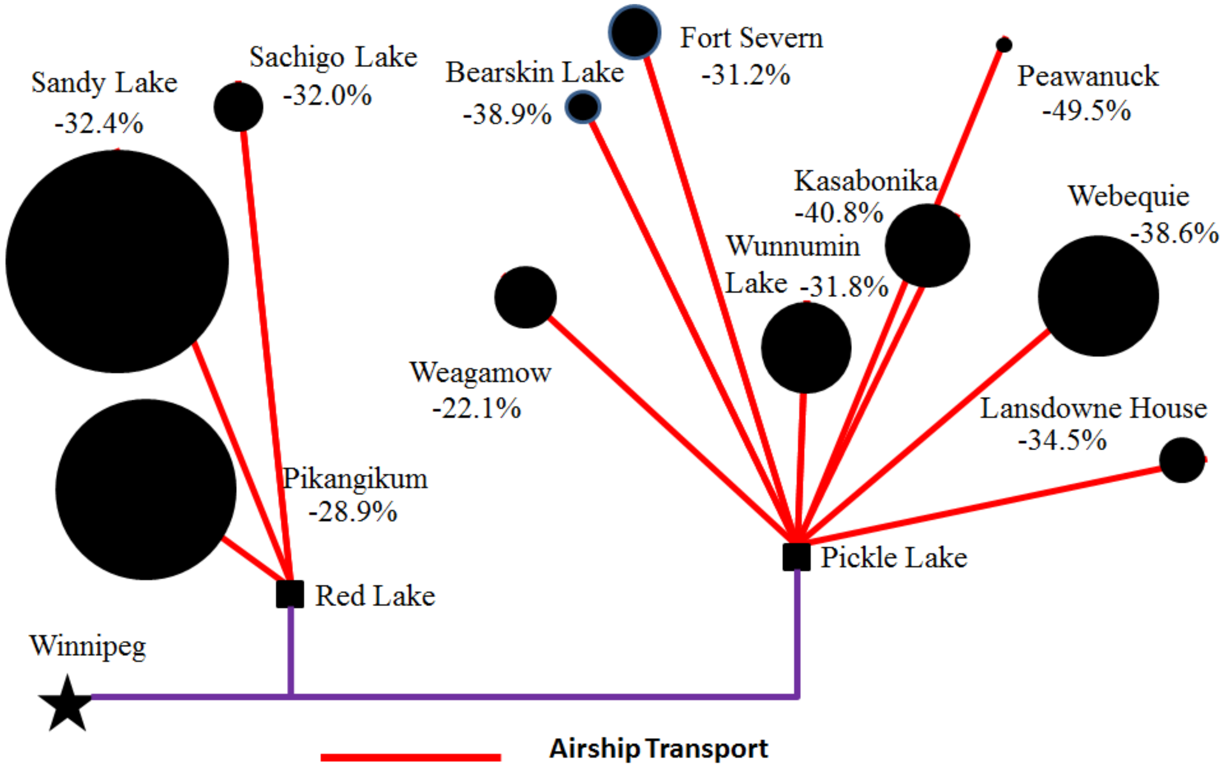
NWON alternative 1 assumes all air freight flows are transported by cargo airship while winter road trucking flows remain unchanged. The results are presented in Figure 10. Cost savings for all communities range between approximately 33% and up, to almost 50%. The weighted average cost savings for all communities is 38.3%. Serving the NWON region in this alternative requires a total of 328.9 BH and 430.4 OH. 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, 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 transport airship activity (75.7 BH and 98.6 OH) while Peawanuck accounts for the least (10.6 BH and 12.1 OH). Total cargo airship MTK is almost 0.87 million.

Figure 10 – Transport Airship Alternative 1 for NWON Region – With Ice Roads



Alternative 2 assumes all freight is moved by transport airship. The cost savings are summarized in Figure 11. Total annual transport airship utilization increases slightly to 0.99 million, while block hours and occupied hours increase to 378.4 BH and 497.1 OH. The split is a nearly 60/40 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).

Figure11 – Transport Airship Alternative 2 for NWON Region – No Ice Roads



Overall Cost Competitiveness

These case studies can be pooled to develop an analysis of relative transportation cost behaviour of each mode as distance increases. This provides further insight into the performance and competitiveness of transport airships in the carriage of food and general merchandise. Figure 12 illustrates the cost curves for the transport airship, conventional aircraft, ice road trucking, and highway trucking. Cost is measured in dollars per metric tonne over distance in kilometers[7]. The cost curves for existing modes of transportation are linear approximations derived from the dataset provided by the shipper. The transport 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 assuming a fixed volume of traffic.

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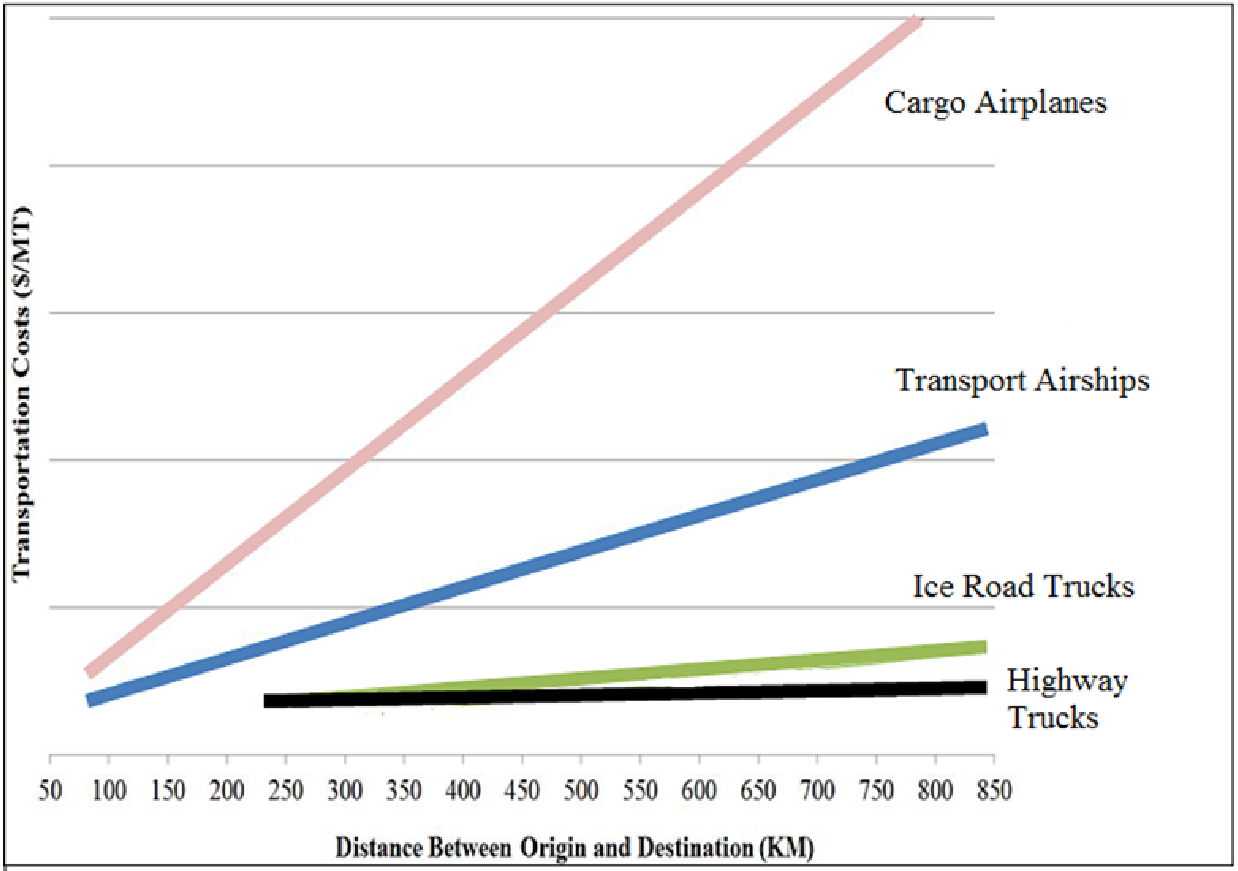
[7] The legend for the Y-axis has been removed for confidentiality reasons.

Figure 12 - Cost curves in Dollars per Tonne for the transport airship, conventional aircraft, ice road trucking, and highway trucking over distance (km).



* The Y-axis has been removed for confidentiality purposes.

Both highway and ice road trucking are less costly than the transport airship when the costs of providing the infrastructure are ignored. The cost competitiveness of trucking versus airships becomes more complicated if the infrastructure cost is recognized. Utilization is the key to the economic trade-off between roads and airships. Given the high fixed costs of road construction, the longer the distance or the fewer the trucks using it, the more competitive is the transport airship (Prentice, et al., 2013). If the cost of infrastructure were included, it would shift of the highway and ice road truck cost curves vertically. Where they cross would indicate the competitive distance for a specific volume of traffic.

The relative economic advantage of the transport airship over conventional aircraft is evident. Conventional aircraft costs rise rapidly as distances increase while transport airship costs increase at a much lower rate. The transport 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 transport airship affords the greatest direct transportation cost savings when used in conjunction with surface modes of transportation if the infrastructure already exists.

CONCLUSION

The analysis reveals that the proposed transport airship design possesses an economic advantage in serving the cargo transportation needs of isolated regions in northern Canada relative to existing modes of transportation. Employing transport airships as part of a multi-modal freight transportation system could reduce freight costs for food and groceries by 31.6% in the ESLW area of Manitoba and 38.3% of the NWON region of Ontario. These cost savings are relative to each region's existing freight transportation system. The economic analysis is based on direct freight transportation costs alone.

Mixed systems are often more efficient than pure systems, and the combination of cargo airships and ice roads would appear to be another example. Transportation costs are minimized when the transport airship is utilized in conjunction with ice road trucks. The cost difference between the transport airship-only system and the combined ice road trucking and transport airship system is significantly higher in the ESLW than in the NWON. The NWON communities are proportionally more dependent on airplanes than the ESLW communities.

The long-term viability of ice road trucking is questionable given the warming climate. Communities that are more dependent on ice road trucking are more vulnerable to rising food cost increases if all freight must be transferred to airplanes. Freight transportation costs would rise by approximately 30% if conventional aircraft are used exclusively for re-supply. Conversely, the availability of transport 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 most severely impacted by the loss of ice roads.

The strength of this analysis is the confidence that can be put in the costs and volumes of shipments to NWC stores. Actual data were made available to the University of Manitoba on a confidential basis. The greatest weakness of the study is the estimated freight costs of the transport airship. Although this research uses a very conservative estimate of airship costs and a non-optimal distribution method, no 50-ton lift transport airships exist to corroborate the cost data. Moreover, the size of the airship used in the study is arbitrarily chosen. Perhaps a smaller airship, say 10 to 25 tons lift, would be more appropriate for the volumes involved.

A number of topics are suggested by this study for future research. For example, regular airship delivery could impact other logistics costs, such as a reduction in inventory holding costs, temporary warehousing, damaged freight, spoilage, shrink, etc. The inclusion of freight volumetric data (cube) would provide a better comparison of the transport airship’s advantage in carrying voluminous cargoes. Inclusion of passenger transportation flows in a combi-service could be examined. The ESLW alone accounted for 110,670 passenger trips in 2000. Finally, the costs of more realistic “milk runs” to serve these communities might be estimated.

Of greatest importance to the people living in Canada’s remote northern communities, this study provides hope that an economic solution exists to the high food prices, which they must endure, and the threat to their ice road life-lines that is posed by climate change.

REFERENCES

Aboriginal Affairs and Northern Development Canada. (2010). Food mail program. Retrieved from http://www.aadnc-aandc.gc.ca/eng/1100100035755/1100100035756

Adaman, Matthew. *Assessing the Cost Competitiveness of a Cargo Airship for Freight Re-Supply in Isolated Regions in Northern Canada.* A Master of Science thesis submitted to the Faculty of Graduate Studies of The University of Manitoba, Winnipeg, Manitoba, 2013.

Air Creebec. (2013). Our fleet. Retrieved from http://www.aircreebec.ca/en/ProductList.aspx?CategoryId=ec1e1946-4386-416e-93b8-7d792dcc098e&ImageWidth=200

Bonomo, F., Durán, G., Larumbe, F., Marenco, J. (2012). A method for optimizing waste collection using mathematical programming: A Buenos Aires case study. *Waste Management & Research, 30(3), p.311-324.*

Buhr, L.A., Krahn, D.P., & Westdal, H. (2000). East Side of Lake Winnipeg: All-weather road jusification and scoping study – Executive summary. Retrieved from http://www.gov.mb.ca/mit/tspd/pdf/studies/east.pdf

Council of Canadian Academies. (2014). *Aboriginal Food Security in Northern Canada: An Assessment of the State of Knowledge.* Ottawa, ON: Report of the Expert Panel on the State of Knowledge of Food Security in Northern Canada. http://www.scienceadvice.ca/en/publications/assessments.aspx

East Side Road Authority. (2011). Proposed all-season road network on the east side of Lake Winnipeg. East Side Road Authority. Retrieved from http://www.eastsideroadauthority.mb.ca/pdf/LATNS_MainRecommendations_Apr2011.pdf

Federgruen, A. & van Ryzin, G. (1997). Probabilistic analysis of a combined aggregation and math programming heuristic for a general class of vehicle routing and scheduling problems. *Management Science , 43(8), p. 1060-1078.*

García, J., Florez, J.E., Torralba, Á., Borrajo, D., López, C.L., García-Olaya, Á., Sáenz, J. (2013). Combining linear programming and automated planning to solve intermodal transportation problems. *European Journal of Operational Research, 227(1), p. 216-226.*

Guilding, C., Drury, C., & Tayles, M. (2005). An empirical investigation of the importance of cost-plus pricing. *Managerial Auditing Journal, 20(2), p. 125-137.*

Keith, H.L. (2001). "Shameful mismanagement, wasteful extravagance, and the most unfortunate dissention": George Simpson's misconceptions of the North West Company. *Oregon Historical Quarterly, 102(4), p. 434-453.*

Laporte, G. (2010). A concise guide to the Traveling Salesman Problem. *The Journal of the Operational Research Society, 61(1), p.35-40.*

Manitoba Bureau of Statistics. (2008). Communities. Retrieved from http://www.gov.mb.ca/mbs/communities/l_list.html

Manitoba Infrastructure and Transportation. (2011). Minister’s annual expense report. Retrieved from http://www.gov.mb.ca/mit/reports/index.html.

North West Company. (2013). The North West Company Inc. 2012 annual report. Retrieved from http://www.northwest.ca/content/annual_filings/2012_ANNUAL_REPORT.pdf

Nutrition North Canada. (2012). About the program. Retrieved from http://www.nutritionnorthcanada.ca/abt/index-eng.asp

Ontario Ministry of Natural Resources. (2013). Facts about our forests. Retrieved from http://www.mnr.gov.on.ca/en/Business/Forests/2ColumnSubPage/STEL02_164508.html

Prentice, B.E., Grewal, N., Doell, B., & Adaman, M. (2013). Cargo airships versus all-weather roads – A cost comparison. Proceedings from the 48th Annual Canadian Transportation Research Forum, 89-104.

Pokrupa, J. (2007). Building construction in the Near North. In Prentice, B.E., & Wylie, G. (eds). Airships to the Arctic Symposium IV: Making it Happen. (94-99). Winnipeg. Retrieved from http://www.airshipstothearctic.com/docs/pr/isopolar_aaiv.pdf

Perimeter Aviation LP. (2009). Charters. *Perimeter Aviation*. Retrieved from https://www.perimeter.ca/charter/charters.html

Queen's Printer for Ontario. (2013). 2010-2011 winter road program. Retrieved from http://news.ontario.ca/mndmf/en/2010/11/2010-2011-winter-roads-program.html

Thompson, I.D., Maher, S.C., Rouillard, D.P., Fryxell, J.M., & Baker, J.A. (2007). Accuracy of forest inventory mapping: Some implications for boreal forest management. *Forest Ecology and Management, 252, p. 208-221.*

Transport Canada. (2013). Canadian Aviation Regulations (CARs) 2012-1: Standard 720 – General. Retrieved from http://www.tc.gc.ca/eng/civilaviation/regserv/cars/part7-standards-720-2153.htm

Wasaya Airways. (2013). Our fleet. Retrieved from http://www.wasaya.com/default.asp?pid=2&cid=158&ref=1

APPENDIX 1: TRANSPORT AIRSHIP COSTING

The analyses use actual freight rates as a baseline for comparison. These freight rates reflect what freight transportation companies charge to shippers to ensure profitability. Transport airship costs are therefore calculated to simulate what a carrier operating a transport 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.

Block hours are calculated as the amount of time that elapses between the transport airship lift-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 transport airship's cruising speed, and the amount of time it takes for lift-off and landing. The cost model specifies 20 minutes each for lift-off and landing and a cruising speed of 125km/h. Net in-flight hours are calculated by subtracting 41.7 km from the trip distance to account for the distance covered during the transport airship's lift-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 are 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*):

$$BHC = B\left(F + M\right)$$

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 transport airship operating costs are assigned to occupied hours. Occupied hours include the time between when the transport 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 transport 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 transport 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*):

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

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.

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*):

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

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 transport airship's payload capacity they use given the assumptions of 100% transport 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 transport 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 transport 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 transport airship possesses an economic advantage over existing modes of freight transportation are as follows:

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