COST COMPETITIVENESS OF RE-SUPPLY VIA CARGO AIRSHIP IN KIVALLIQ, NUNAVUT

Matthew Adaman, Transportation Analyst, The North West Company, Dr. Barry E. Prentice, Professor University of Manitoba and Dr. Paul Larson, Professor, University of Manitoba

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 a myriad of negative impacts on these region's residents. High food prices have given rise to citizen activism (Strapagiel, 2012) and concerns about food security have been the subject of in-depth analysis (Council of Canadian Academies, 2014).

This paper assesses the potential for a cargo airship to reduce the costs of food transportation. The analysis is based on the operations of the North West Company's (NWC) grocery distribution system in the Kivalliq region of Nunavut. The logistics costs for a proposed 50-tonne lift cargo airship are compared to existing logistical systems. The analysis begins with a description of the Kivalliq region and the NWC shipping data. Subsequently, four alternative logistical scenarios are examined for a 50-tonne lift cargo airship.

Kivalliq is the most southerly region of Nunavut, but it is still remote. Its total surface area is 445,109 km^2. Arviat, the nearest community to Winnipeg, is 1,263 km away by air. The NWC operates retail food and general merchandise stores at Rankin Inlet (population: 2,358), Arviat (2,060), Baker Lake (1,728), Coral Harbour (769), Repulse Bay (748), and Chesterfield Inlet (332). The total population of these six communities is 7,995 people. Figure 1 presents a sketch map of the Kivalliq region.

Nunavut relies heavily on air transport for re-supply. Communities with relatively long airstrips can be served by aircraft like the Boeing 737-200 combi-airplanes. They have maximum payload capacities of 14 tonnes. Communities with shorter airstrips are served by mid-size regional aircraft like the ATR-42 and ATR-72, capable of carrying maximum payloads of 4.5 and 7 metric tonnes, respectively.

The NWC is the largest food retailer in Nunavut. In the study period, they shipped 3,303.0 tonnes of freight to six community stores: 2,178.4 tonnes (66%) by air and 1,124.6 tonnes (34%) by sea. Of this total, 2,806.5 tonnes is food and 496.5 tonnes is general merchandise.

Figure 1. The Kivalliq Region, Nunavut

While the majority of the NWC airfreight is shipped from Churchill (1,503.5 tonnes), a significant volume comes directly from Winnipeg (539.1 tonnes). All maritime freight originates in Valleyfield, Quebec (1,124.6 tonnes). Data based on the April 2010 – March 2011 period.

Staging freight at the trans-shipment points in the network requires the use of rail and highway trucking. These modes are referred to as surface intermodal (SIM). There are four paths through the re-supply network and each varies in terms of modal split. Table 1 shows the SIM paths.

Table 1. Surface Intermodal Paths on the Routes to Nunavut

Origin	Destination	Mode	Quantity (tonnes)
Winnipeg Montreal	Montreal Valleyfield	Rail Truck	1,124.6
Winnipeg Thompson	Thompson Churchill	Truck Rail	1,503.5
Winnipeg	Thompson	Truck	103.8
Winnipeg Edmonton	Edmonton Yellowknife	Truck Truck	31.9

Air freight flows and costs include both the SIM and air transport portions of the trip, whereas the maritime freight flow is direct from Valleyfield, Quebec to the Nunavut communities. The NWC is charged a flat rate per sea container irrespective of destination. Although air transport is more costly than maritime transport, the differential between these two modes is not as extreme as might be expected *a priori*. The cost of maritime transport on a per tonne-mile basis is significantly lower than air transport, but the long distances to the communities narrows the difference.

Air transport costs account for approximately two-thirds of total transportation costs. When trucking costs are added, this rises to 87.6% of full landed cost. Maritime freight accounts for approximately one-third of the total quantity of freight shipped to Kivalliq and 12.4% of total annual transportation costs.

Cargo Airship Operating Cost Model

Several cargo airship developers were contacted to provide operating cost data, but only one provided useful information for calculating cargo airship trip costs. The cargo 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 cargo 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 cargo 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 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. 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.

Because the shipper requested all dollar amounts remain confidential, the operating costs of the cargo airship in dollar amounts must also remain confidential. Table 2 describes the general operating characteristics of the cargo airship.

Table 2 - The cargo airship's general operating characteristics and finance terms.

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

The cruising speed of the cargo airship is 125 km/h and it has a useful payload capacity of 50 metric tonnes (MT). The vehicle 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. The cargo airship's operating costs are outlined in Table 3.

Table 3 - 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 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%

Total operating costs include variable and fixed costs. Fuel consumption and maintenance requirements are variable cost drivers that accrue with each block hour[i]. 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 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 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 cargo 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 cargo 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.

Cargo Airship Logistical Alternatives

The availability of maritime freight transportation to Kivalliq presents an interesting logistical comparison. Two different conditions are included in the design of the four cargo airship alternatives. The first condition is that the cargo airship is used to replace conventional aircraft for the air freight flows, but the maritime flows remain fixed. 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. Moreover, the additional freight quantity provided by the shift from maritime to the cargo airship has practical implications. The increased quantity of freight ensures greater utilization of a cargo airship which helps to spread its fixed costs.

The most dramatic changes of eliminating sea shipments 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.

One issue common to all scenarios is pilot duty time limitations. 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 that conventional aircraft regulations, apply also to the cargo airship. Therefore, pilot costs are doubled 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.

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. All freight originates at Winnipeg and is trans-shipped at Churchill, which is closest to Kivalliq and maximizes the land transport. Total cargo airship utilization attributable to re-supplying the Kivalliq region is approximately one million metric tonne-kilometres (MTK).

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 Arviat from Churchill requires 6.2 occupied hours.

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 second logistical alternative also assumes that maritime freight flows 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 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 first to a central hub at Arviat. Subsequently, the cargo airship is used to transport freight from the trans-shipment point at Arviat to the other Kivalliq communities.

Arviat is selected as the regional hub in this scenario based on the minimum-cost distribution point model found in Harris (1954). 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 the following equation.

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

$P_i =$ 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

Harris's model was modified to incorporate 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.

Freight is transported from Winnipeg to Churchill by surface inter-modal means (SIM). The cargo airship ferries the freight to Arviat, and from there 1,314.2t of freight are transported by cargo airship to other Kivalliq communities. The use of Arviat as a hub has an additional benefit because the quantity of air freight demanded at this outlet is the highest of all the stores in Kivalliq. This minimizes the volume to be trans-shipped within the region.

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.

Although the freight transportation system is restructured in alternative 2 (hub & spoke), the cost calculation is the same as for alternative 1. The same modes are used in this alternative as in alternative 1 with altered routing.

It is worth noting that in the baseline scenarios, 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.

The next two scenarios assume that all maritime freight is shifted to the cargo airship. Alternative 3 is relatively similar to the first scenario. All freight is transported from Winnipeg to Churchill, and from Churchill all freight is transported to the Kivalliq communities by airship. Pilot costs are doubled in this scenario for any flights with total trip times over 8 hours.

Under this scenario, the additional freight quantity results in a significant increase in airship utilization. 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. The cost comparison for alternative 3 is between the cargo airship system without maritime transportation and the baseline system.

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 Kivalliq community, it is necessary to determine which of the communities should serve as the hub. 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.

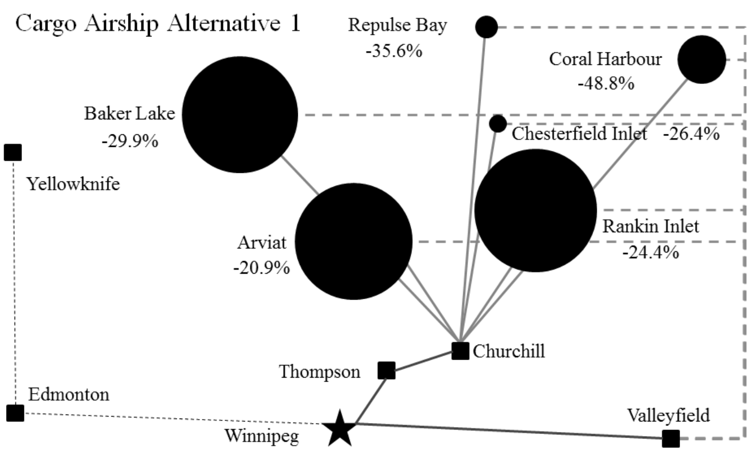
The resulting freight re-supply network is identical to the hub and spoke network model in the Alternative 2 with the exception that maritime freight flows are not present. Freight is transported from Winnipeg to Churchill by SIM. Freight is then transported from Churchill to Arviat and then to each community by cargo airship.

For this alternative, 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 excluded.

Summary of Results

The circles in each diagram represent the size of the communities. The cost changes relative to the base line for transporting food and grocery merchandise are printed beside each community. In Alternative 1, all air freight is transported by cargo airship from Churchill. The maritime freight flows are represented by the dashed lines from Valleyfield, Quebec.

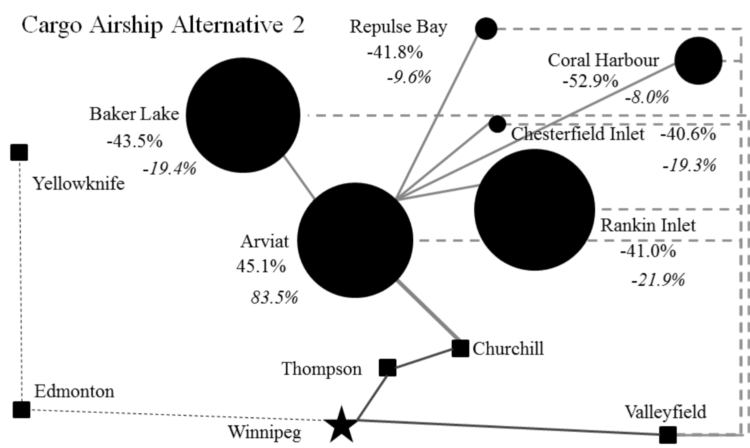
Nearly one million MTK of service are provided to the region. A total of 347.6 block hours and 404.4 occupied crew hours are accrued over a total of 43.6 trips. Arviat, Baker Lake, and Rankin Inlet account for almost three quarters of cargo airship trips, while Chesterfield Inlet, Coral Harbour, and Repulse bay each require between one and two trips per year. Trips to Baker Lake, Chesterfield Inlet, Coral Harbour, and Repulse Bay all require a two-pilot flight crew.



The cost impacts of the cargo airship in Alternative 1 are as follows: 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.

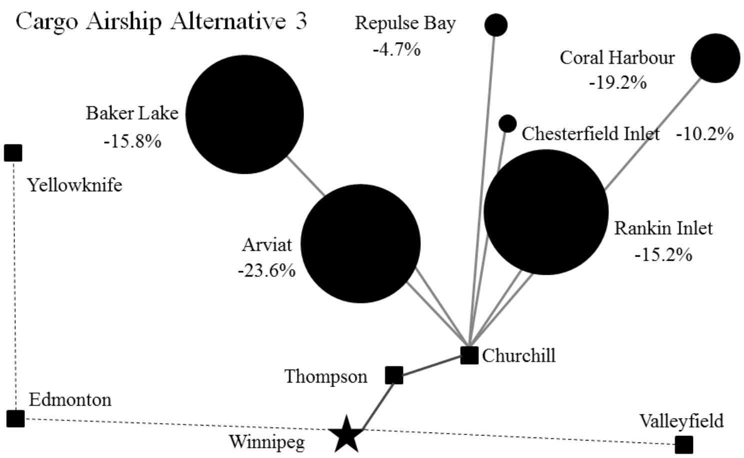
Alternative 2 is the hub and spoke system with maritime freight flows. Note that the flows to Arviat originate in Churchill while the flows to other destinations originate in Arviat. Total block hours and occupied hours are 372.9 and 463.8 respectively. Note that the only two-pilot crews required in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

The largest cost changes between Alternative 2 and the baseline scenario 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%.

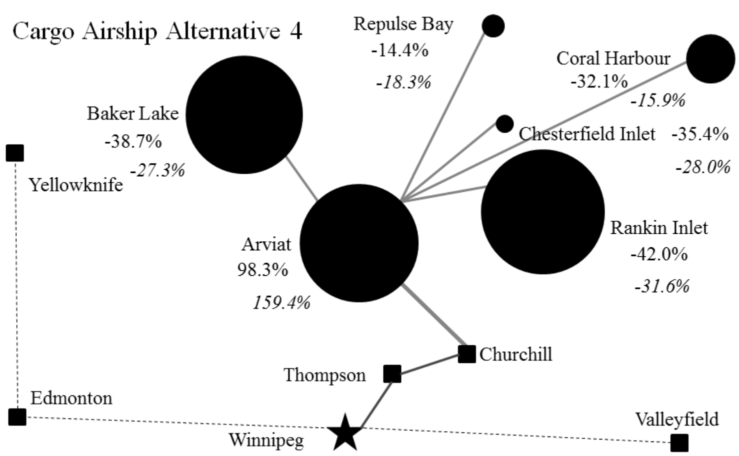


The cost comparison between Alternative 2 and Alternative 1 is illustrated in italics. Transportation costs to Arviat are 83.5% higher in Alternative 2 than in Alternative 1 while transportation costs drop in all other communities. The net effect, however, is that Alternative 2 is 5.3% more costly than Alternative 1.

For Alternative 3, cargo airship MTK increase 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 from Churchill. Trips to Baker Lake, Chesterfield Inlet, Coral Harbour, and Repulse Bay require a two-pilot flight crew.



Without the use of maritime freight transport, total transportation cost savings provided by the cargo airship are only 16.4%, versus 29.8% when combined with sea transport.



Finally, for Alternative 4, 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.

For Alternative 3, total cost savings for the NWC across the region amounts to only 9.2%. The transportation cost savings from diverting all freight to the cargo airship are lower than when the hub and spoke network is used. Alternative 4 is 8.6% more costly than Alternative 3. These cost changes for each community are contained in the italics.

Discussion of Results

Mixed systems are often more efficient than pure systems, and the combination of cargo airships and maritime freight transportation would appear to be another example. Transportation costs are minimized when the cargo airship is utilized in conjunction with maritime freight transportation. The benefit to the region of using cargo airships over airplanes is a reduction of 29.8% per year in the total cost of transporting food and general grocery merchandise.

The greatest cost savings on the transportation of groceries are achieved when the cargo airship is operated directly from Churchill to each community rather than the hub and spoke system. The additional costs of employing a two-pilot crew are less than the extra costs of trans-shipping merchandise a second time at Arviat.

The availability of cargo airship freight transportation service would have impacts on the cost of food distribution that extend well beyond the direct transportation cost savings discussed here. 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. 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. The NWC also incurs additional administrative costs to manage winter road trucking and maritime transport when they are available. The elimination of these costs could be included in a future costing analysis to determine how a cargo airship could reduce the prices paid for food in Canada's remote northern communities.

Another area for further research is a volumetric data analyses. The weight-density of food and groceries shipped by the NWC is often relatively low, e.g. lettuce, corn flakes, bread and diapers. An advantage of cargo airships over existing aircraft is that they offer significantly more volumetric capacity. Airplanes are more likely to "bulk-out" before they "weigh-out", than cargo airships. The reduction in the number of airship flights (relative to airplane flights) would further lower the food transportation costs of the NWC and other shippers to Kivalliq. The inclusion of volumetric data would provide a more accurate measure of cargo airship competitiveness.

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[i] Block hours include the time between when an aircraft sets into motion until when it comes to rest at the end of a trip.