

CARGO AIRSHIPS VERSUS ALL-WEATHER ROADS - A COST COMPARISON

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Introduction

Resource companies experience severe logistical challenges operating in Northern Canada. Developments in remote areas face high transportation costs, difficulty moving physically large cargo, and the extreme seasonality of ice roads and barge transportation. The cost of all-weather road construction and the lead-time for environmental approval can prevent otherwise viable projects from moving forward. These transportation and logistics barriers negatively impact the profitability of resource development projects.

A new generation of cargo airships is emerging that have the potential to reduce economic barriers for mines that otherwise must build all-weather road infrastructure or rely heavily on ice roads. The purpose of this report is to evaluate the economic conditions under which cargo airships can provide improved transportation services to mining operations in Northern Canada.

This paper uses financial models to determine the break-even volumes that are required for airship operations to compete with trucks on all-weather roads at varying haul distances. The next section presents a conceptual framework. Subsequently, a brief survey of cargo airship developments is presented along with the method of analysis and a description of the cargo airship and truck costs. The analysis is applied to two separate mining scenarios with varying cost assumptions. The article concludes with a discussion of the contextual issues and topics for further research.

Transport Options in Northern Canada

Airplanes and all-weather roads are the only means of year-round re-supply in Northern Canada. Most remote communities have gravel landing strips, but only the largest centres are connected by all-weather roads. Marine transport is available during the summer in the coastal markets of the Arctic Archipelago, Hudson Bay and Labrador. Inland from the coast, there are few all-weather roads. Winter road trucking is possible in most areas, but the duration of ice roads is unreliable. Rail transportation is nonexistent in remote northern areas except for a few lines in Alberta, Manitoba, Ontario and Quebec. Canada's most attractive mineral resource developments are located far beyond the permanent infrastructure and remote communities.

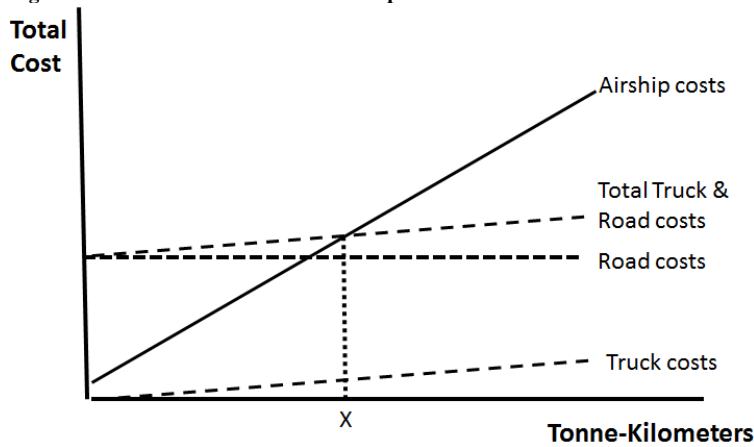
Airships have the potential to compete with trucks, where new all-weather roads must be constructed. The cost of building a gravel road in the boreal forest areas runs between \$1.6 million and \$3 million per kilometer depending on the terrain, number of water crossings, swamps and muskeg. Additional costs may be incurred if road construction encounters permafrost soils. The total cost per truckload depends on the utilization of the all-weather road.

A new generation of cargo airships is emerging that expands the options for transport in remote areas. An attractive feature of airships is their flexibility. They are able to carry loads of all shapes and configurations to remote locations that lack the infrastructure required for traditional forms of transportation. They are particularly competitive in the carriage of low-density cargo because they can have large cargo bays and can carry awkwardly shaped freight as slung loads. The first generation of cargo airships is expected to have a payload capacity between 20 and 50 metric tonnes (MT).

The comparison of intermodal competition usually involves an analysis as illustrated in Figure 1. Roads have high capital costs that must be incurred upfront. Although annual maintenance is required, the total costs of a road are more or less constant for a given length. Truck costs increase with the number of tonne-kilometers carried as more trucks are added to carry greater volumes. Airship costs are also

a function of the volume carried because infrastructure requirements, other than a hangar (airdock), are minimal. At some point, as the utilization of the road increases, the costs of the airship and the trucks are equal. This is denoted by the point “X” on the diagram. To the left of the X, it is less expensive to use airships, while trucks and the road are lower cost if the traffic volume is greater than at this point.

Figure 1: Theoretical cost tradeoff: airships versus all-weather roads and trucks



All weather roads are sensitive to the economies of traffic density. The tonne-kilometer cost of a gravel road depends on the initial construction costs, maintenance required, and its expected useful life. A resource road that ceases to operate during its useful life because of a mine closure is a stranded asset with zero value. The tonne-kilometer cost of trucking is higher if the mineral resource is short-lived, if the volume of traffic is low or if the distance is longer. In general, the competitiveness of trucks and cargo airships is specific to the location and the density of traffic.

Cargo Airship Developments

Cargo airships have been in development for several years, and despite the broad interest, no commercially certified vehicles have entered into commercial service. However, this is about to change

because of the military investments in the United States that have been occurring in the development of lighter-than-air technology over the past six years. The leading cargo airship developments are listed in Table 1 with a classification on their structure, projected cargo capacity, method of buoyancy control and the status of each project.

Table 1: Cargo Airship Developments Worldwide, as of 2012

	Structure	Useful Lift	Buoyancy Control	Project Status
HAV (UK)	Non-rigid Catamaran	50 T	Heavier-than-air	Military Prototype
Lockheed-Martin (USA)	Non-rigid Catamaran	20 T	Heavier-than-air	Scaled Prototype
Worldwide Aeros (USA)	Rigid Catamaran	20 T	Partial Gas Compression	Scaled Prototype
RosAeroSystems (Russia)	Rigid Round top	20 T	Partial Gas Compression	Design
VariaLift (UK)	Rigid Cigar-shape	50 T	Full Gas Compression	Concept Validation

Non-rigid airships depend on a pressure differential between the atmosphere and the lifting gas inside the ship to maintain the shape of the hull. Rigid airships have a stiff outer shell, or hull, that is non-pressurized. The lifting gas is contained in gas cells within the hull.

Buoyancy control is necessary to be able to transfer a load, land and take-off. The non-rigid catamaran shapes, generally called hybrids, are heavier-than-air when unloaded, and depend on engine thrust to gain altitude via their aerodynamic shape. Rigid airships can use lifting gas compression to control their buoyancy. By moving gas out of their gas cells into pressurized holding tanks the airship becomes heavier, and vice versa.

Methodology

The following analyses are conducted to examine the contextual circumstances in which a cargo airship would be the least-cost mode

of transportation in a mining operation. Annual transportation costs are calculated for the cargo airship and for a trucking option under which the mining company would be responsible for the cost of the road's construction and its annual maintenance. These cost calculations are based upon the freight transportation requirements of two mines in northern Ontario.

The calculation used to determine which of the two modes of transportation is least expensive in terms of annual costs is given as $AC_D = AC_T - AC_A$ where AC_T is the annual cost associated with trucking, AC_A is the annual cost associated with cargo airships, and AC_D is the differential between the two. If AC_D is positive, then the cargo airship is the least cost alternative and vice versa if negative. Break-even occurs when AC_D equals 0. Annual transportation costs are not discounted to their present value in the analyses that follow.

Trucking Costs

Trucking costs comprise both variable haulage costs and the fixed costs associated with road construction and maintenance. For all scenarios, the variable trucking cost is set at \$0.145 per MT-KM. It is assumed that trucking capacity is available linearly. In other words, this freight rate would apply even for less-than-truckload quantities. Annual road maintenance is also fixed in all scenarios at \$7000/KM.

Road construction costs are varied to test the effect of this cost factor on the location of the break-even point. Analyses for all scenarios are conducted at road construction costs of \$1.6M/KM and \$3.0M/KM. Annual costs associated with road construction are calculated as the total cost of the road divided by the road's expected lifespan. For example, the annual cost associated with a road 100KM long at a cost of \$1.6M/KM and a lifespan of 10 years would be \$16M/Year.

Cargo Airship Costs – The VariaLift ARH50

The operating and ownership costs associated with the cargo airship are provided by VariaLift for their ARH50 model. This airship is a

rigid, all-aluminum construction that possesses a patented system that compresses and decompresses its lifting gas to control buoyancy. The modular design and aluminum envelope allow for lower fabrication costs and ease of mass production.

VariaLift has built a segment of the airship and has successfully demonstrated its buoyancy control system. This is a vital step in the process towards fabricating an ARH50 prototype, given that most remaining structure and propulsion systems are based on well-established engineering knowledge. The operating parameters and assumptions data provided by VariaLift are listed in Table 2.

Table 2: ARH-50 VariaLift Study Specifications

Length (m)	150
Span (m)	52
Max payload (metric tonnes)	50
Cruise speed (km/hr)	190
Purchase price (Cdn \$)	\$30,000,000
Life of airship (years)	40
Insurance rate (Hull)	10%
Insurance rate (PL)	5%
Helium leakage (annual)	1%
Vertical take-off and landing (VTOL)	Yes
Estimated fuel consumption l/hr	900
Flight crew	2
Ground crew, mechanics, etc	4
Airdock (hangar) construction cost (Cdn \$)	\$28,000,000

Airship costs comprise both variable costs and fixed costs. The fixed costs are accrued irrespective of whether or not the airship is operating. These fixed costs include lease costs for the airship and airdock, employment of personnel, helium, and insurance. The variable costs include certain maintenance items, fuel consumption, and flight fees.

Operating Context – The Tale of Two Mines

The quantitative analysis considers two different mining operations in Northern Ontario. The Victor Mine is a diamond mine served by an ice road from the rail head at Moosenee, Ontario. The Black Thor mine is a large chromite deposit, located in an area known as the Ring of Fire. The diamond mine lies in the Hudson Plain Ecozone, while the chromite deposits are near the western boundary of this region. The road construction challenges for the Hudson Plain are expected to be greater because of permafrost and more water crossings. It is assumed that both of these mines would operate continuously, 365 days per year.

Characteristics of these two mine scenarios are summarized in table 3. Some assumptions are made to provide a range for the analysis. For example, the life of the Black Thor mine is assumed at 25 years in comparison with 10 years for the Victor Mine. The Black Thor mine can take advantage of existing infrastructure, while the Victor mine must build the entire road length. The airship flight distances are similar.

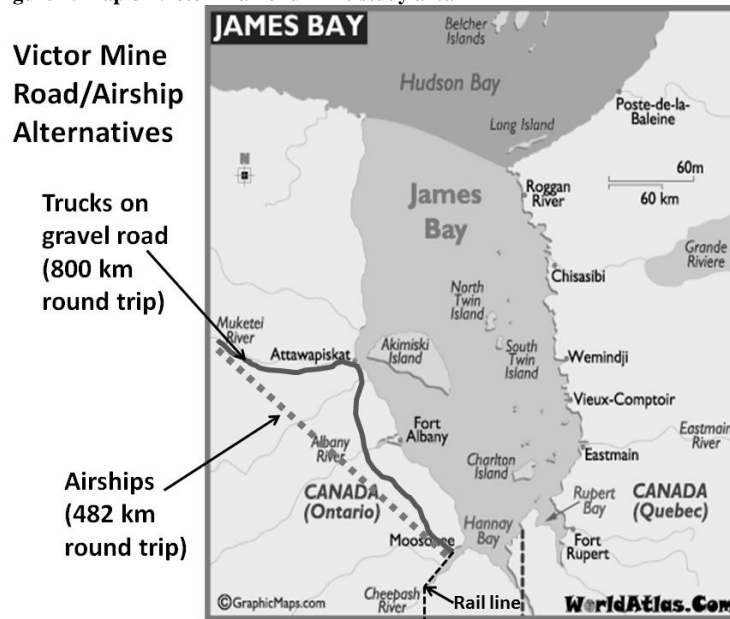
Table 3: Black Thor and Victor Mine characteristics

Characteristics	Black Thor	Victor Mine
Truck Trip Length (KM)	680	800
All-Season Road Length (KM)	260	400
Lifespan of Road (Years)	25	10
Airship Trip Distance (KM)	510	482
Airship Trip Length (Hours)	4.35	4.2
Maximum Airship Trips per Day	5	5

The map of the road/airship alternatives to the Victor mine is illustrated in figure 2. All goods are assumed to move by rail to a transloading point in Moosenee. The gravel road is assumed to follow the path of the current ice road route via Attawapiskat that is approximately 400 km long. The airship route would be direct from Moosonee to the Victor Diamond mine, and is 241 KM in length. A

round-trip by trucking would be 800 km whereas by the airship it would be 482 kilometers.

Figure 2: Map of Victor Diamond Mine study area

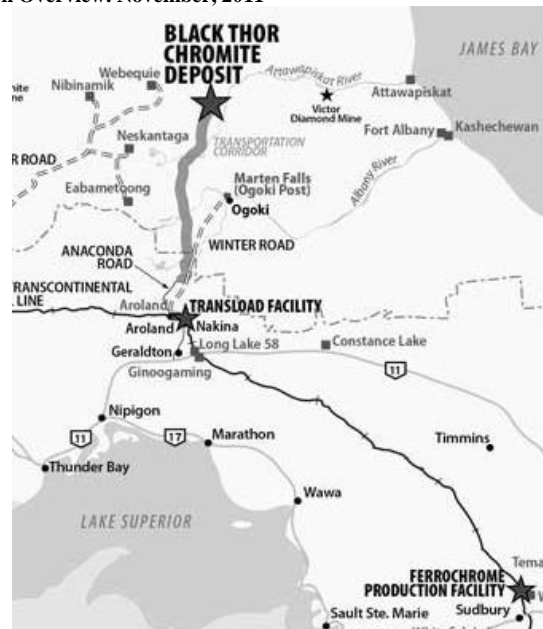


The map of the road/airship alternatives to the Black Thor mine is illustrated in figure 3. The Ring of Fire deposit containing nickel, copper, platinum, and palladium was announced in 2007. The Black Thor Chromite prospect has an estimated 72 mega-tonnes of chromite ore. ¹ Cliffs Natural Resources' (CNR) plans to establish a chromite smelter in Sudbury and a transload facility in Aroland, Ontario. The transload facility would be at the intersection of the CN Transcontinental Rail Line and Ontario Road 643. The facility would be north of Highway 11, the northernmost highway in Ontario.

When operational, the Black Thor mine would produce 3,600 to 7,200 tonnes of concentrate daily. The distance for the airship to complete a round-trip is 510 km whereas for a truck the distance to

the transshipment point is 680 km. The mine needs to construct 260 km of gravel road to serve this property. The cost of the road is amortized over 25 years, the expected life of the mine.

Figure 3 - Map of Black Thor Region. Source: Cliffs Chromite Project: Project Description Overview. November, 2011



Results

The annual costs for each mode of transportation are calculated for each mine scenario. The analyses are based on low/high road construction costs of \$1.6M/km and \$3.0M/km. The results for Victor Mine are illustrated in figures 4 and 5.

This first set of results is for the Victor Mine at road construction costs of \$1.6M/KM. The cargo airship is the superior alternative up to between 720,000 MT/year and 800,000 MT/year freight transportation demand. This translates into between approximately

1,973 MT/day and 2,192 MT/day output from the mine. The trucking alternative dominates at all quantities of freight above that.

Figure 4 - Victor Mine scenario, \$1.6M/KM road-build costs

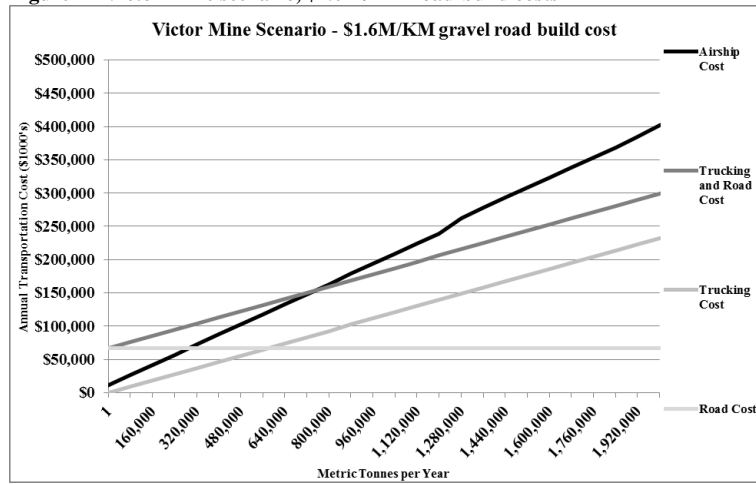
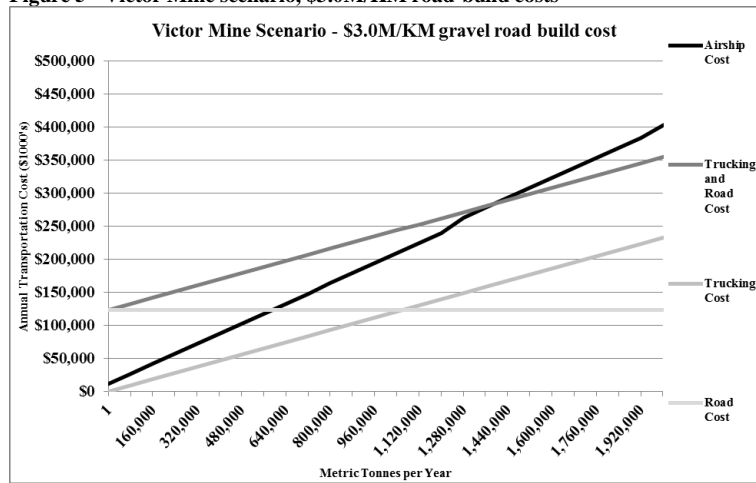


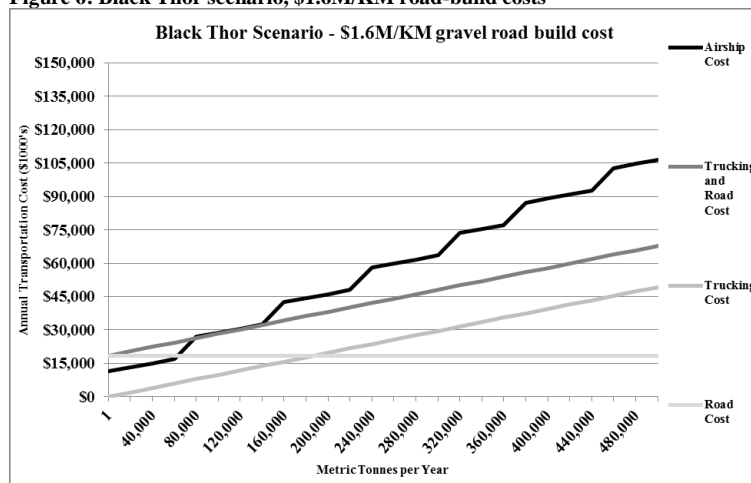
Figure 5 - Victor Mine scenario, \$3.0M/KM road-build costs



When road construction costs reach \$3.0M/km, and all else remains fixed, the cargo airship is the least cost alternative at much higher output levels. In this case, the cargo airship is the least-cost alternative until output reaches between 1,360,000 MT/year and 1,440,000 MT/year, or between 3,726 MT/day and 3,945 MT/day respectively. Beyond this, the trucking alternative would be the least-cost alternative.

In contrast to this, the results from the Black Thor scenario illustrate a strikingly different competitive outcome. The results for the Black Thor scenarios at \$1.6M/km and \$3.0M/km road construction costs are illustrated in figures 6 below and 7 on the following page.

Figure 6: Black Thor scenario, \$1.6M/KM road-build costs

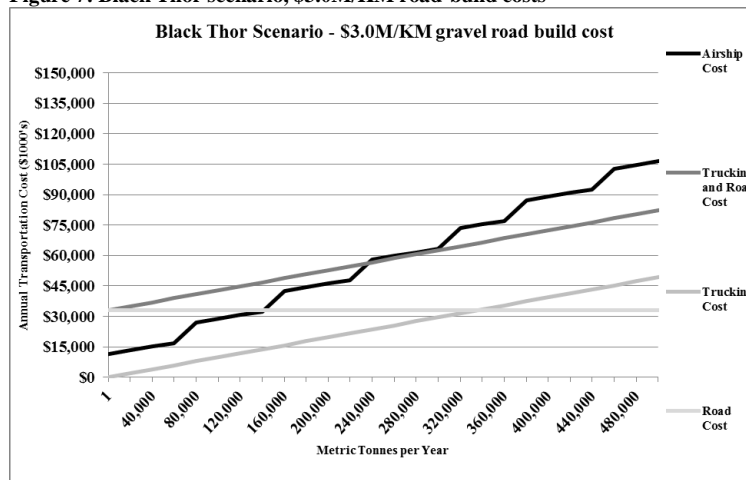


In this base-case, the cargo airship is the least-cost alternative at the lower end of the output quantity range. The lumpiness observed in the cargo airship cost curve is due to the addition of airships to an expanding fleet, something that is necessary when the freight demand exceeds the transport capacity of the existing fleet. The break-even point of the existing fleet occurs between 60,000 MT/year and 80,000 MT/year, or 164 MT/day and 219 MT/day respectively. However, the cost advantage of the trucking alternative is relatively small until 160,000 MT/year

when an additional airship is required to meet freight transportation demand. For the majority of the range along the X-axis, the trucking alternative dominates.

The results of changing road construction cost to \$3.0M/KM are illustrated in figure 7. In this case, the cost-competitiveness of the cargo airship increases significantly. The break-even point occurs between 220,000 MT/year and 240,000 MT/year, or 603 MT/day and 657 MT/day respectively. At volumes greater than approximately 240,000 MT/day, the trucking alternative would be the least-cost option.

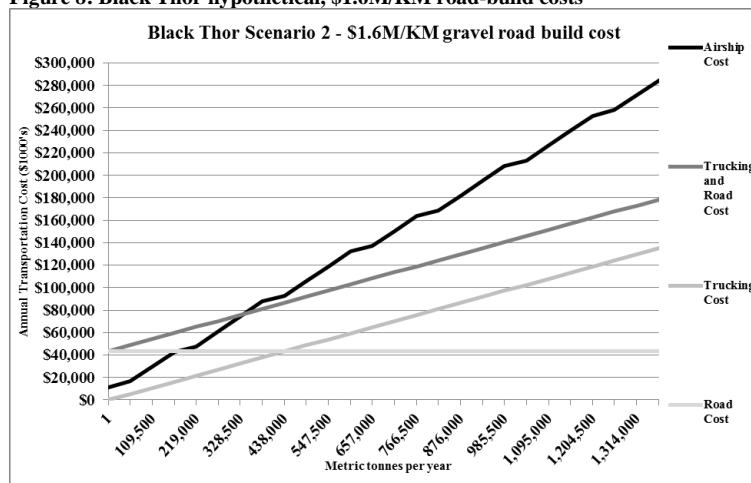
Figure 7: Black Thor scenario, \$3.0M/KM road-build costs



Comparison of the results obtained from the two scenarios provided evidence that the cargo airship would be most competitive in serving short-lived mining projects. Although slight differences in road and trip length exist between the two scenarios, the most significant difference is that the Victor Mine is expected to be operational for 10 years in comparison with 25 years for the Black Thor mine. This motivated the analysis of a third hypothetical scenario in which the Black Thor mine only lasts for 10 years instead of 25. The results are presented in figure 8.

Decreasing the lifespan of the Black Thor mine to 10 years results in an upwards shift in the annual road cost curve. The break-even point occurs between 328,500 MT/year and 383,250 MT/year, or 900 MT/day and 1050 MT/day. This represents an increase over the baseline Black Thor scenario of between 380% and 450% in freight volume.

Figure 8: Black Thor hypothetical, \$1.6M/KM road-build costs



Analysis conducted when the road construction costs are \$3.0M/km (not shown) results in a similar increase; the break-even point occurs between 657,000 MT/year and 711,750 MT/year. In comparison, the break-even point occurred in the baseline scenario between 220,000 MT/year and 240,000 MT/year.

Discussion and Topics for Future Research

The results from these preliminary analyses provide insight into the contextual factors that favour cargo airship use. In all scenarios, the cargo airship is the least-cost alternative when the volume of freight is relatively low. The cost of building a private road is high and can only be justified when there is sufficient utilization. The cargo airship could allow small deposits of minerals to be developed that would

otherwise be uneconomic given the cost of truck transportation and road construction.

The cargo airship appears most suited to mining operations with short expected lifespans. The cost of building a road is much higher per tonne-kilometre if the mine is forced to leave a stranded asset. When the expected lifespan of a mine is low, the cargo airship may make an otherwise uneconomic property worthy of development. Moreover, some jurisdictions require remediation of the road that can add to the costs of mine closure, a fixed cost that would be more significant for short-lived, low-volume mines in comparison with long-lived, high-volume mines.

The length of the road has a direct impact on the competitiveness of the cargo airship. Clearly, there is no simple cut-off length in which an airship is going to be less expensive than building a road, but in general, the longer the distance, the more likely a cargo airship will be preferred.

An aspect of this analysis that deserves more attention is the time-value of money. It is possible that the competitiveness of the cargo airship would improve given the length of time it takes to obtain all the necessary approvals and construct an all-season road. It is not uncommon for mining operations to experience two to four years of delay just to complete the environmental assessments and sort out land claims.

Airships could enable mining operations to enjoy positive cash-flow earlier, while putting off the date at which they need to commit all their capital costs for a road. Normally, mines begin with surface pits and mine out the ore that is available before beginning underground operations. Airships could lift in heavy equipment, a concentrator and permit operations to begin. It is also possible that the airships could accelerate the construction of the road. Being able to drop off equipment and materials to build bridges could speed up the construction phase of the road.

Another aspect of mining that should be considered is opportunity costs. Typically, mining booms are cyclical. When metal prices are high, companies can obtain investors and begin the development of new production. However, it is also the case that many mines are closed before the ore bodies are completely exhausted because mineral prices have collapsed to the point that it is no longer economic. The ability to open a mine sooner could enable the mining company to capture more of the “high price” years of the resource cycle by more closely aligning the peak of mineral prices with the peak of mine output.

The flexibility of the airship is also important with respect to mineral prices. Once a mining company has committed to the construction of a road and opened the mine, it may be forced to operate with low margins for a long period in order to recoup the capital it invested in the road infrastructure. The airship is a mobile asset. Once the mine no longer justifies the expense of the airship, it can be relocated to another site where the economics are favourable. When mineral prices improve, the airship can always be brought back.

The cost comparison of cargo airships versus all-weather roads suggests that in some cases either mode of transport may provide the least cost solution; however, a strong case can be made for using both modes together in certain situations. Once airships become operational and their costs can be defined with greater precision, it will be possible to identify the opportunities for the Canadian mining sector. The most intriguing finding from this paper is that the cargo airship may permit a whole new type of mining operation, one focused on extracting small, isolated pockets of resources that would otherwise be too costly to bring to market.

Acknowledgement

This paper is based on a larger and more detailed study that was commissioned by the Moose Cree First Nation in 2013. Any errors or omissions are the responsibility of the authors.

ⁱ (<http://www.republicofmining.com/2008/07/28/northern-ontarios-ring-of-fire-mineral-discovery-sets-off-staking-rush-gregory-reynolds/>)