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Modeling multimodal freight transportation scenarios in Northern Canada under climate change impacts

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ABSTRACT

In Canada's Northwest Territories, goods are delivered to remote communities and natural resource extraction sites by inland barge, trucks, and for some goods, air. Combinations of all-weather and winter roads are used in the winter months, while river barge transport and all-weather roads are used in the summer. However, Northern Canada is disproportionately impacted by climate change, which results in greater variability in water level conditions on the Mackenzie River from year to year. This in turn critically affects tug-and-barge operations on the river. This paper investigates Mackenzie River Corridor freight delivery performance – with a focus on the river route – considering how variations in river water conditions can impact network operations and operational costs. We investigate the impacts of water level variation on shippers' route choice decisions, waterway supply capacity and the resulting overall performance of the freight transport system. Model outcomes provide insights into how the multimodal transportation network may be utilized and perform (quantified by delays and generalized costs) under different water level scenarios. The overarching purpose of the analysis is to provide guidance for infrastructure investment decision-making and business case development, to maintain an effective freight transportation network in the face of on-going climate change impacts.

1. Introduction

In the Northwest Territories (NWT) of Canada, particularly along the Mackenzie River Corridor, goods are delivered to remote communities and natural resource extraction sites by different modes depending on the season. River transport and all-weather roads are used in the summer, combinations of all-weather and winter roads are used in the winter months, and highly expensive air transport can be used year-round. However, Northern Canada is heavily and disproportionately impacted by climate change, which also results in greater variability in conditions from one year to the next. Water conditions on the Mackenzie River are no exception to this phenomenon. Water conditions critically affect tug-and-barge operations on this river, which is considered an "ultra-shallow" inland waterway, and is a historically heavily relied-upon mode of goods transport. A recent study demonstrated the Mackenzie River flow regime to have changed over the past four decades due to climate variation, with decreases in maximum spring flows, and rise in cold season base flows (Yang, Shi, & Marsh, 2015). Also, critically low water levels on the Mackenzie in the summer of 2014 made that delivery season one of the worst in many years, with severe delays, much undelivered (by barge) freight, and barges "trapped" downstream. We anticipate conditions such as those experienced 2014 to occur more frequently in future years; as a result, measures to better adapt to greater variations in water conditions is necessary for waterway freight transport to continue. The purpose of this paper is to examine Mackenzie River Corridor freight delivery performance – particularly that of the marine route – considering how variations in river water conditions affect network operations.

A model is built to investigate the operational and cost impacts of water level variation on shippers' route choice decisions, waterway supply capacity and the resulting overall performance of the freight transport system connecting remote communities along the Mackenzie River and coastal communities in the Beaufort Sea. We consider a multimodal transportation system including waterway, all-weather roads, and winter roads. We construct water levels scenarios and waterway capacity scenarios based on historic water levels data to study the impacts of climate uncertainty (Jonkeren, Rietveld, & van Ommeren, 2007). The former is used to assess shippers' potential choice of delivery mode based on perceived and anticipated waterway delivery reliability (with respect to delays as well as the probability of non-delivery). The waterway freight capacity scenario tree is constructed based on historical water levels, barge loading capacities and drafts, fleet availability, and geographic characteristics. Resulting scenario delays and generalized costs are assessed to measure system performance, and provide insights into how the multimodal transportation network may be utilized and perform under different water conditions scenarios. This analysis may provide the Government of the Northwest Territories guidance about where transportation infrastructure investments may be most

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needed, and help provide business cases for these investments, in order to maintain an active and competitive transportation network that can help to stabilize living costs as well as promote economic activities in the face of on-going and rapid climate change impacts.

2. Context & background

The transportation system in Northern Canada must be as reliable and cost-effective as possible, despite the harsh climate conditions, in order to keep remote but well-established communities, natural resource extraction sites, and research stations connected to major supply chains in the south. It is also important to the Government of Canada in exercising its sovereignty over Arctic lands and waters (Government of Canada, 2015). The Mackenzie River – the longest and largest river system in Canada, with a watershed that covers almost 20% of the country – is a major historic transportation route through the Northwest Territories. The river flows northbound, starting from Great Slave Lake and emptying at Tuktoyaktuk into the Beaufort Sea. Transportation on the Mackenzie River corridor consists of the river itself during the summer ice-free season, winter roads that are constructed on a frozen foundation of ice and snow in the winter season (December through March/April), plus a network of all-weather roads. There is a plan to connect the entire corridor by all-weather road within the next decade.

Tugs and barges are used to deliver a variety of community supplies (personal and commercial), equipment for natural resources development and other ancillary goods, and bulk fuel along the Mackenzie River and to coastal communities in the Beaufort Sea. Dry cargo (community resupply) for the Mackenzie River and Western Arctic communities originates in Edmonton, Alberta. Petroleum, Oil and Lubricants (POL) is delivered from refineries in Edmonton, the United States, and other offshore sources in Europe or Asia (S A, 2015).

The transportation network connecting communities along the river and those in the Arctic coastal region (including the Kitikmeot Region of Nunavut) that have typically been served via the Mackenzie River freight delivery system[1] are shown in Fig. 1.

Freight deliveries on the network shown in Fig. 1 originate upstream (i.e. south) along the river or from British Columbia and Yukon via Inuvik. There are several waterway freight transportation companies that operate on the Mackenzie River, with the largest being the Northern Transportation Company Limited (NTCL). NTCL's main terminal is located in Hay River. Here, goods arrive via rail or truck, are transshipped to barges, and then delivered to communities and mine sites downstream on the river and to coastal communities in the Beaufort Sea. Although they deliver to over 80 destinations, major destinations having annual volumes over (and sometimes, well over) 2000 tons each, consisting of 86% of NTCL's total annual freight volumes (Northern Transportation Company Ltd., 2015a, 2015b), are identified in Fig. 1. The coastal communities identified by the orange shading in Fig. 1 are reached by transshipping to an ocean-going barge at Tuktoyaktuk. Another operator on the Mackenzie River is Cooper Barging Service Limited (CBSL; www.cooperservices.ca/); all-weather road is used to access their terminal at Fort Simpson, where goods are transshipped to river barge and delivered to communities along the river to Norman Wells.

Deliveries to Inuvik can be made year-round via the Dempster Highway from Dawson City, Yukon. In addition, during the winter months, some communities along the river can also be reached by winter roads.

3. Literature review

There has been much recent attention in the literature on climate change impacts on transportation systems performance, and transportation network resiliency in the face of both major weather events as well as growing variability in day-to-day operating conditions. Much of this literature focuses on dense urban networks, as well as important interurban (freight delivery) networks. Koetse and Rietveld (2009) indicated that there are three major methods used to examine the influence of climate change on transport. The first is to compare the performances of transport systems in regions with very different climate conditions, although difficulties arise in identifying and controlling for other factors that impact these systems such as economic situations and physical conditions. The second is to assess seasonal variations in transportation systems performance and travel behavior due, in turn, to variations in and cycles of weather and demand. The third is to consider the instantaneous impacts of weather on travel behavior, which are likely to be clearly visible but very short-term as well.

Another approach taken by Jonkeren, Jourquin, and Rietveld (2011) was to construct climate scenarios based on different levels of global temperature increases and extents of change in atmospheric circulation (i.e., wind direction) to characterize climate change on the Rhine River in the Netherlands. Climate change has impacted water levels on the Rhine River, a historically highly reliable, safe, and cost effective freight delivery route connecting major ports in the Netherlands and Germany to the hinterlands. In fact, inland waterways such as the Rhine and Danube are vulnerable to many types of extreme weather events (Schweighofer, 2014). With low water levels, vessels' cargo carrying capacity may be limited, while sailing times may increase due to low water effects on ship hydrodynamics (Schweighofer, 2014).

Jonkeren et al. (2007) looked at the freight price effects and therefore, welfare effects, of low water levels (impacting trip capacities) on freight transport along the Rhine River. They estimated that the average annual welfare loss over 20 years, due to low water levels, was about 28 million euros (Jonkeren et al., 2007). Cost implications of climate change and adaptation were further studied in 2013 (Jonkeren, Rietveld, Ommeren, & Linde, 2013). In addition, European river delivery modes compete heavily with parallel truck and rail routes, and therefore, freight mode shift (to rail and truck, away from waterways) due to increasing delays and travel time unreliability is a significant concern in this dense and demand-heavy European network. Previous studies exhibit considerable differences in the effects of attributes used to explain freight route and mode choice. The most commonly considered attributes of mode and route choice are cost, travel time (or speed), and travel time reliability (Cullinane & Toy, 2000; Wigan, Rockliffe, Thoresen, & Tsolakis, 2000). Hendrickx and Breemersch (2012) documented the interdisciplinary ECCONET project, which aimed to comprehensively account for the impacts of climate change on transportation infrastructure for economic evaluation and policy implications. Simulation was used to determine freight modal shifts to rail and road, from the Rhine and Danube, due to climate change (Beuthe, Jourquin, Urbain, Lingemann, & Ubbels, 2014).

The Government of Canada has also been concerned about climate change in the north, the impacts to all aspects of northern life and activities, and adaptation measures (Warren & Lemmen, 2014; Lemmen & Bourque, 2008). The physical and economic impacts of warming, with particular focus on the transportation system, were explored as early as 1993, using a scenario approach based on global circulation models (Shinghal & Fowkes, 2002). The authors used analytic models to assess the impacts of these climate change scenarios, and mention that data availability was a significant issue. More recently, Borkovic, Nolet, and Roorda (2014) assessed the financial risk in continued sole reliance on winter roads for diamond mining transport. They looked at the impacts of climate change on winter road duration and load capacity, and in turn, the economic impacts of air lifting goods not able to be delivered by winter road.

In this paper, we present an analysis procedure that can provide assessments of future variations in waterway shipping conditions due to climate change, that impact the traditional mode of river freight transport. We represent the multimodal network in order to study the effects of climate variation not only on demand (through modal shifts) but also on waterway capacity.

[1] These communities in the NWT and Nunavut were traditionally connected via the Mackenzie River and air only; however, with the opening of the Northwest Passage, since 2009 these communities have also been reached by sealift from the east.

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