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Railroad transportation of crude oil in Canada: Developing long-term forecasts, and evaluating the impact of proposed pipeline projects

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ABSTRACT

Rail crude oil shipments have witnessed a steady increase over the past decade, which underscore the long-term viability of this transport mode. Although incidents involving these shipments could be catastrophic, having link-level information could be useful for designing appropriate emergency response network and responding to such episodes. We present a data-driven methodology that makes use of analytics to estimate the amount of crude oil on different rail-links in Canada until 2030. The resulting analyses facilitated identifying high-risk links around Canada based on the current practice of the railroad industry, and to suggest that incurring marginally higher transportation costs could reduce network risk. In addition, the availability of the proposed pipeline infrastructure would change the supply and demand location configurations over the forecast horizon, with the maximum changes to the current crude oil traffic flow pattern stemming from the completion of the Energy East pipeline project.

1. Introduction

Crude oil, the lifeblood of the modern economy, accounts for the largest share of the total world primary energy demand, and is forecasted to remain so until 2040 (IEA, 2016). Canada has the third largest reserves, and is the sixth largest global producer of crude oil. In 2016, crude oil production totalled 3.85 million barrels per day in Canada, and is expected to increase to 5.12 million barrels per day by 2030 (CAPP, 2017). Approximately 94% of the crude oil production, both from conventional technique and from oil sands, takes place in the two western provinces of Alberta and Saskatchewan, which are then transported to refineries to produce gasoline and fuel oil (NEB, 2016a). It is important that both these provinces are landlocked with no direct access to water transportation infrastructure, and primarily relies on pipelines to access refineries located in different regions of Canada and the United States. In addition, technological advances over the past decade have facilitated vast and economically viable production of crude oil (and gases) from tight and shale formation in Alberta (Canada) and in the Dakotas (United States), thereby yielding unprecedented excess supply. However, the near capacity utilization of the existing pipelines and the lack of access to water transportation infrastructure necessitated using alternative modes of transportation to move the excess supply to refineries. The economies of scale and the ability to move to different markets in response to demand rendered railroad as a viable alternative for moving bulk crude oil shipments. As a result, in Canada, rail transport of crude oil saw an impressive increase from 500 carloads in 2009 to over 130 K in 2016 (Lavelle, 2013), and has been steadily increasing except a minor blip stemming from the wildfire episode in Alberta in 2016 (CAPP, 2017). Note that the preceding statistic underlines the long-term viability of this alternate transport mode, which in part was shaped by the proactive efforts of the railroad industry to respond to this opportunity by introducing unit trains that are formed at the loading terminals and travel non-stop to the refineries (i.e., demand locations), thereby eliminating the need for any intermediate yard operations and making the overall duration of a given trip much shorter.

It should be evident that unit trains provide economies of scale because a large volume of crude oil could be shipped together. However, crude oil is a hazardous material (hazmat), and could potentially be dangerous to human life and the environment. The inherent risk associated with such trains carrying crude oil (and any other hazmat) cannot be underestimated, even given the good safety statistics of railroads (Verma and Verter, 2013), or the low probability –high consequence nature of multi railcar incidents (Sherali et al., 1997). For instance, the most catastrophic incident in recent history involved the derailment of a unit train carrying 72 railcars of crude oil from the bakken shale region of North Dakota (United States) to the largest refinery in Canada, i.e., Irving refinery in Saint John on the east coast of Canada. 63 of the derailed railcars leaked about six million litres of crude oil, and the resulting fire and explosion left 47 people dead in a

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small town of Lac-Megantic in the eastern province of Quebec (TSB, 2014). The investigation report prepared by the Transportation Safety Board of Canada, among other things, recommended that Transport Canada more actively monitor the railway safety management system; and, that emergency response assistance plans must be created for large volumes of liquid hydrocarbons such as crude oil (TSB, 2014). This study makes the first effort to estimate an important input that would facilitate both the recommended actions, and answer the following research questions. *What is the volume of crude oil on various rail-segments in Canada? Is it possible to mitigate network risk by developing better shipment plans? What is the likely impact of the proposed pipeline projects?* Such a study is especially crucial because, in spite of the rich academic and industry engagement in the assessment and management (mitigation) of hazmat risk for rail shipments, the true potential benefits could not be demonstrated in the absence of reasonable estimates about hazmat volume. Having relevant information about hazmat volume (and type) would not only facilitate more precise risk analysis but also ensure a more effective emergency response network that could successfully contain hazmat incidents before they become catastrophic. For example, the catastrophe from the Lac-Megantic train disaster could have been alleviated if precise details about the quantity of crude oil (i.e., hazmat volume) were available and appropriate emergency response network was in place. Unfortunately, that was not the case, and procuring pertinent information from reluctant (and un-cooperative) railroad companies was extremely difficult. Given the challenge of procuring information from the railroad industry, most of the published academic work assumed either random data or 12% of railroad freight as an estimate for hazmat traffic (TSB, 2004). However, if the railroad industry seeks to gain a larger share of the crude oil shipments and become a viable alternative to pipelines, it should be mandated to provide pertinent details (i.e., volume, hazmat type, and routes) to help develop appropriate emergency response plans.

We make the first attempt to estimate crude oil traffic at rail links and rail yards in Canada, and propose a methodology that contains five steps: *first*, analyze historical data on crude oil shipments; *second*, select appropriate models for short-term and long-term forecasting; *third*, develop forecast; *fourth*, employ different schemes to route traffic; and *fifth*, estimate crude oil traffic at various rail links and yards. The proposed methodology was used to study a number of problem instances in Canada, which were analyzed: to identify the locations with high exposure to crude oil traffic, and thus provide the possible inputs for developing emergency response plan; to discern the impact of shifts in supply locations, and the relative exposure to crude oil shipments of different rail yards and links from 2018 to 2030; and, to evaluate the impact of proposed pipeline projects on rail crude oil shipments. It is important that the proposed methodology is robust enough to be applied to other countries, however, appropriate modifications that capture the topography of the country would have be made.

The rest of the paper is organized as follows. Section 2 reviews the relevant literature, followed by a detailed discussion and illustration of the proposed data-driven methodology in Section 3. Implications of the current practice of the railroad industry, ways to reduce network risk, and the impact of the proposed pipeline projects are discussed in Section 4. Finally, conclusion and directions of future research are outlined in Section 5.

2. Literature review

The relevant literature is organized under three themes: the *first* part will be related to freight traffic forecasting; the *second* part will review risk assessment efforts in railroad and pipeline transportation of hazmat; and, the *third* will briefly discuss works specific to crude oil movements by rail and pipeline.

2.1. Freight traffic forecasting

One of the earliest works on freight transportation forecasting resulted from the endeavour to develop long-term forecasts for energy resources, including crude oil, in France (Chateau and Lapillonne, 1978). In general, freight traffic models can be classified into aggregate and disaggregate categories, wherein the former has a cost-minimizing focus whereas the latter could be tailored to accommodate the behavioral realities of the decision maker (Winston, 1983). If extensive disaggregate data is available, then a number of classes of freight forecasting model could be developed (Chow et al., 2010). Alternatively, passenger forecasting models with appropriate modifications to incorporate the specificities of freight (De Jong et al., 2004), or spatial qualities of centrality and intermediacy could be used to locate strategic places within a transportation system in terms of traffic levels (Fleming and Hayuth, 1994). Finally, some transport geography researchers have opined the need for empirical investigations involving the entire value chain (Hesse and Rodrigue, 2004).

2.2. Risk assessment in railroad and pipeline transportation

A number of approaches to assess rail hazmat risk have been proposed in the literature. The most popular measure, i.e., *traditional risk* defined as the product of the probability and the consequence of an undesirable event, was originally developed in the highway domain but later adapted to incorporate the characteristics of railroad accidents. For instance, Verma (2011) proposed an expected consequence approach using conditional probabilities of derailment and release, and incident consequences following hazmat release from multiple sources. Dearth of data and/or limitations associated with the expected consequence approach has led to the development of alternative risk measures such as *incident probability* that neglects the incident consequences (Abkowitz, Lepofsky, & Cheng, 1992), and *population exposure* that only focuses on the consequences (Verma and Verter, 2007). Finally, Hosseini and Verma (2017, 2018) have proposed assessment methodologies that incorporate the catastrophic nature of hazmat shipments, such as the Lac Megantic incident. We note that all these efforts were at a network level and that the usefulness at a rail-link level is only as accurate as the parameters assumed as inputs.

Pipeline has been a popular research area over the past few decades (Papadakis, 1999), where investigations ranged from risk assessment to product scheduling (MirHassani and Ghorbanalizadeh, 2008). However, the primary focus has been on using risk assessment methodologies to examine the probability of pipeline failure (Restrepo et al., 2009), wherein the engagements range from using historical oil spill data (Gujit, 2004) or fault tree analysis technique (Yuhua and Datao, 2005) to estimate failure probabilities, to examining the basic reasons for failure (Dziubinski et al., 2006). Most recently, risk assessment efforts have focused on severe accidents (Bonvicini et al., 2015). For example, quantitative risk analysis techniques were applied to pipelines (Han and Weng, 2011), and Bayes theorem was used to estimate the distribution of severity (Eckle and Burgherr, 2013).

2.3. Comparing railroads and pipeline for crude oil shipments

It has been established that pipelines enable transportation of fuels at cost, i.e., environmental and social impacts (Rabinov, 2004), even when future cleaner ground transportation alternatives are considered (Strogen et al., 2016). It is interesting that, just for oil sands, it has been contended that rail can be more cost-competitive when compared to even large-diameter pipelines (Fielden, 2013). Most recently, after examining the Canadian oil sands industry, Verma et al. (2017) concluded that pipelines are relatively more cost effective at large production scales, but less at smaller production quantities. Contrary to the assertion of some authors (MirHassani, 2008), nothing definitive can be said about the safety of pipelines vis-à-vis railroads. For instance, a Fraser