Project Summary – Transport Canada

Analysis of Fluidity Indicators and Seasonality Adjustments for Containers Transit Times in Multi-Modal Supply Chain Networks

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CLIENT ORGANIZATION

Now, more than ever, Canadians need a safe and secure transportation system. Transport Canada (TC) is a government agency that is responsible for transportation systems, policies and programs. It promotes safe, secure, efficient and environmentally-responsible transportation within Canada and reports to Parliament and Canadians through the Minister of Transport.

As a result of ensuring a safe and secure transportation system, TC's work protects people from accidents and exposure to dangerous goods, protects the environment from pollution, and contributes to a healthy population and economy. TC is also responsible for the safety and security of activities including: aircraft services, rail, road and marine safety, and transportation of dangerous goods.

PROJECT INTENT, SCOPE, AND OBJECTIVES

Supply chains play a crucial role in the transportation of goods from one part of the world to another. As the saying goes, "a given chain is only as strong as its weakest link" – in a multi-modal context, comparing the various transportation segments is far from an obvious endeavour.

TC is looking to produce an index to track container transit times in multi-modal chain networks. This index should depict the reliability and the variability of transit times but in such a way as to be able to compare performance between differing time periods. The seasonal variability of performance is relevant to supply chain monitoring and the ability to quantify and account for the severity of its impact on the data is thus of great interest.

The ultimate goal of this project was to compare quarterly and/or monthly performance data, irrespective of the transit season, in order to determine how well the network is performing, as it applies to the *Shanghai → Port Metro Vancouver/Prince Rupert → Toronto* corridors, and to produce a scoring methodology which could then be applied to other corridors.

METHODOLOGY

In order to complete the assignment, CQADS used the following methodological steps:

1. *Review transportation literature*, in order to develop a scoring methodology to determine which is most relevant. The scoring methodology was applied to several proposed indicators that were developed for the *Shanghai – Port Metro Vancouver – Toronto* corridor.
2. *Review and explore available transit time data* to identify seasonality components, leading to adjusted data elements and to the elimination the variability component attributable to such trends.
3. *Testing various pre-existing reliability/variability indicators* against collected container transit time data, which identified promising leads.
4. *Development of the conceptual time-series model,* which established the logic and interaction between the proposed model indicators, and identified the essential data elements providing the best fit to the available data.
5. *Implementation of conceptual model* on a SAS platform, which allowed for the recognition that indicators which best reflected the performance of the chain in a given link were not necessarily the best choice for other links, and led to a new iteration of the prototype model.
6. *Final validation of the prototype model* using collected container transit time data, adjusted to reflect all the underlying trends that had been discovered.

7. *Documentation of the final model*: a technical report providing a detailed description of the model, as well as a number of useful scoring examples, was written and delivered to TC stakeholders. Quality assurance was insured by getting the report summarized and reviewed by a third party, external to the project.
8. *Knowledge transfer* was achieved through regular phone meetings and email exchanges detailing the project progress, and by getting the report reviewed and summarized by external parties.

PROJECT SUMMARY

The supply chain under investigation has Shanghai as the point of origin of shipments, with Toronto as the final destination; the containers enter the country either through Port Vancouver or Prince Rupert. Containers leave their point of origin by boat, arrive and dwell in either of the two ports before reaching their final destination by rail. The situation is illustrated in Figure 1 below.

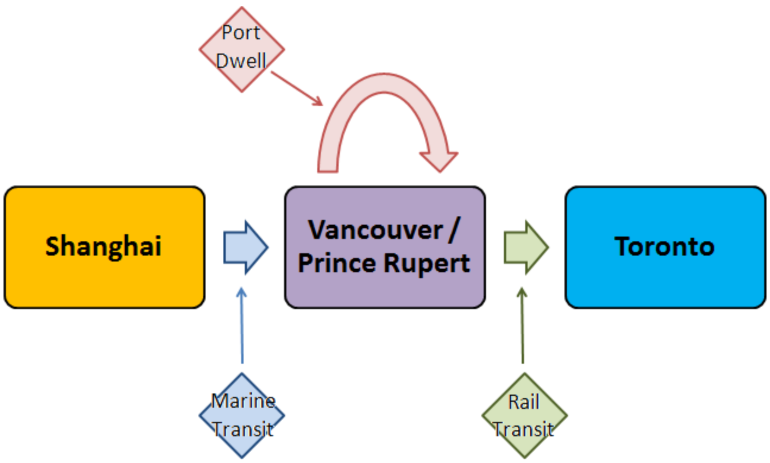

Figure 1 – The Shanghai → Vancouver/Prince Rupert → Toronto supply chain.

For each of the three segments (Marine Transit, Port Dwell, or Rail Transit), the data consists of the monthly empirical distribution of transit times from January 2010 to March 2013 (for Port) or April 2013 (for Marine and Rail), built from sub-samples (assumed to be randomly selected and fully representative) of all containers entering the appropriate segment.

Each segment's performance was measured using Fluidity Indicators, which are computed using various statistics of the transit/dwelling time distributions for each of the supply chain' segments. The main indicators under consideration were:

- the *Reliability Indicator* (RI) is the ratio of the 95^{th} percentile to the 5^{th} percentile of transit/dwelling times. A high RI indicates high volatility, whereas a low RI (≈ 1) indicates a reliable corridor;
- the *Buffer Index* (BI) is the ratio of the positive difference between the 95^{th} percentile and the mean, to the mean. A small BI (≈ 0) indicates that the mean and the 95^{th} percentile transit times are roughly the same, and so that there is only slight variability in the upper (longer) transit/dwelling times; a large BI indicates that the variability of the longer transit/dwelling times is high, and that outliers might be found in that domain;
- the *Coefficient of Variation* (CV) is the ratio of the standard deviation of transit/dwelling times to the mean transit time.

The time series of monthly indicators (which are derived from the monthly transit/dwelling time distributions in each segment) were then decomposed into their Trend, Seasonal (Seasonality, Trading-day, Moving-holiday), and Irregular components (see Figure 2, next page, for an example).

The Trend and Seasonal components provided the expected behaviour of the indicator time series; the Irregular components arose as a consequence of supply chain volatility.

Broadly-speaking, the decomposition involved three main steps:

1. the selection and application of a **seasonal decomposition model** (either additive or multiplicative), through *graphical inspection* (multiplicative if the size of seasonal peaks and troughs changes as the trend changes, additive otherwise) and/or *AICC comparison* (using the SAS procedure `X12`);

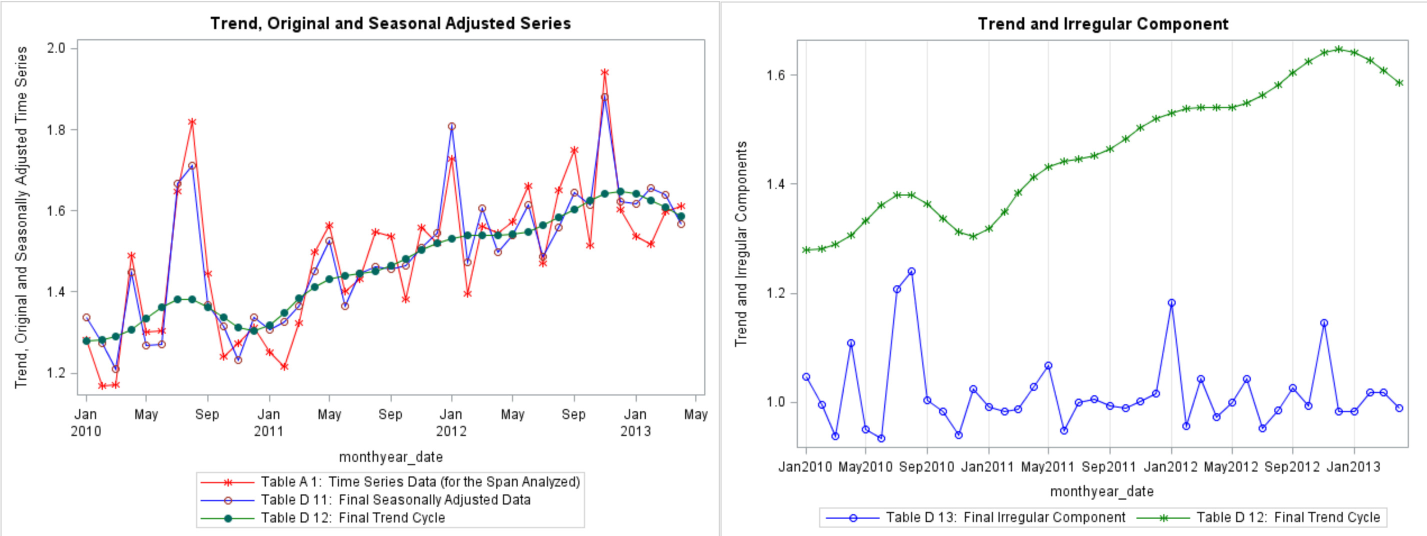

Figure 2 – Indicator time series for Marine RI (Shanghai → Vancouver) in red**.** The Trend component is shown in green, the Irregular one in blue.

2. the identification of, and adjustment (as required) for **calendar effects** such as **trading-day effects** (the effect of the monthly number of weekend days) or **moving-holiday effects** (due to Easter, for instance, in the Western world, or the Chinese New Year in the Pacific Rim), using *spectral plots*, *AICC tests* and *graphical inspection of diagnostic plots;*
3. the identification of, and adjustment (as required) for **trend level shifts** (abrupt but sustained changes in the underling level of the time series which usually have an identifiable cause, such as an increase in shipments due to an extra terminal having opened) and **outliers** (extreme values which fall outside the general trend pattern which can be caused either by an extreme random effect or an identifiable reason such as a short strike or a bad weather event), using *month-to-month percentage changes* and *residual patterns*.

Time series decompositions, and hence any activity depending on them (such as forecasting, for instance), ultimately rely on the quality of the underlying data. In particular, there are a number of well-known data quality issues which affect the results of the analysis:

- the method of data collection may lead to unusual effects, especially if collection is made on a non-calendar basis or if there is a lag between activity and measurement;
- any change to the method or timing of data collection could lead to the false identification of trend or seasonal breaks;
- some series are sensitive to events such as extreme weather, strikes, wars, etc., which could cause breaks or outliers of large magnitude;
- at least 5 years' worth of data are required to insure stability on future updates, and
- at least 10 years' worth of data are required to insure that the adjustment of the first year is unlikely to be revised.

The last two of these did apply to the indicator time series, but were not deemed problematic in the long term as the data collection program from which the data was obtained was slated to continue indefinitely.

A larger issue, and one that it is more difficult to ignore, is that transit/dwelling times are only available for a sample of all containers going through the supply chain, and it is not at all obvious that this sample is randomly selected by the relevant authorities (and so may fail to be representative). Even if it was randomly selected, there is no guarantee that the sampling has remained (or will remain) the same over time.

Consequently, the analysis results were only ever as good as the quality of the data that went into the model. Since the aim of the project was solely to provide a methodology for time series decomposition – rather than to highlight particular irregular values on specific indicator time series – the issue is of lesser consequence at this stage. But this will have to be resolved one way or another by TC and its clients.

There were no overarching results that apply to all indicator time series, on each segment (save for the lack of effect of the Chinese New Year, surprisingly enough): there were series with an Easter effect for a given indicator but not for another; series with a trading-day effect in a segment but not in another; series with outliers and series without, series with a trend level shift and series without.

Another issue is that the reliability of a supply chain is a function of the total transit time from its origin to its destination. The importance of obtaining end-to-end data (i.e., of following a container from one end to another) has been recognized recently, and this data will be used in the analyses when enough of it becomes available. For the time being, however, the segmented data must somehow be joined together, one after the other, in order to provide approximate end-to-end data.

Once the seasonal adjustments are made on the segmented data (i.e. the Marine transit, Port dwelling, and Rail transit time data), we construct an **aggregate indicator** (or index) using these seasonally adjusted segmented indicators as a (necessarily poor) substitute for a direct end-to-end indicator, the underlying argument being that the total fluctuation for the supply chain should be the sum of the fluctuations from the segments since the supply chain as a whole is made up of the individual transportation modes.

Hence, the aggregate index is conceptualized as a weighted average of the indices of the component transportation modes:

$$I_t^A = \frac{\sum_j I_{j,t} \times W_{j,t}}{\sum_j W_{j,t}},$$

where

- I_t^A is the aggregate index for the entire supply chain at time t;
- $I_{j,t}$ is the component index for the specific transportation mode (or segment) j at time t (one of RI, BI or CV, say), and
- $W_{j,t}$ is the weight assigned to mode j at time t (the weights must be internally consistent from mode to mode in order for the weighted average to have meaning).

For a given supply chain, the average transit time in each mode is considered a good candidate for the weights $W_{j,t}$ since it functions as a reflection of the importance of the specific transportation mode to the entire supply chain, and since the average transit time of the entire supply chain is the sum of the average transit time of the individual component transportation modes. Had financial data been available, the **value-added** (the product of quantity and price) would also have been a good choice.

In the absence of financial data, however, we may suppose that the cost of a container spending a certain amount of time in a given mode is proportional to the amount of time spent in that mode (with the understanding that the proportionality constant may differ from mode to mode); as such, it makes sense to use $W_{j,t} = q_{j,t} \times T_{j,t}$ where

- $q_{j,t}$ is the quantity of containers through mode j at time t, and
- $T_{j,t}$ is the average amount of time spent in mode j at time t.

With these assumptions, the aggregate index is eventually defined as

$$I_t^A = \frac{\sum_j I_{j,t} \times q_{j,t} \times T_{j,t}}{\sum_j q_{j,t} \times T_{j,t}},$$

although it is important to note that there is no easy way to validate this formula without end-to-end data.

After seasonality adjustments, it also became possible to compare the performance of (and hence to attempt to differentiate) the various indicators (RI, BI, CV) on a segment-by-segment basis:

- *Marine Transit* – all indicators show increasing trends in the Shanghai → Vancouver channel, and they all identify an outlier for MAY2011 in the Shanghai → Prince Rupert. In both channels, RI had a less volatile seasonal component, while BI had a less abnormally irregular component. It was thus not possible to cleanly rank RI and BI, but the adjusted data suggested that CV would be a poor selection as the indicator of choice.
- *Port Dwelling* – BI was seen to be the less volatile of all indicators, in both Vancouver and Prince Rupert.
- *Rail Transit* – RI was shown to be less volatile in the Prince Rupert → Toronto channel, but not enough data was available to come to a conclusion in the Vancouver → Toronto channel.

The importance of eventually collecting end-to-end data was made clear, as no clear-cut consensus for all segments emerged, apart from the unsuitability of CV as an indicator.

A number of supply chain scoring metrics (scaled scores, comparison scores) were also provided (pitting the adjusted expected data against the actual data in different ways), but before 5-years' worth of data is available, it is a somewhat artificial endeavour to select the optimal one.

ISSUES

The short timeline allocation (see Project Logistics, below) was a consequence of a now-discontinued internship program, in which promising graduate students were hired as interns by CQADS to work on small projects and paid at a discounted rate in exchange for course credit. Consequently, the project dollar value (see Project Logistics, below) was about a fourth as large as it would have been under normal conditions.

Under these same normal conditions, the Centre would have negotiated a 3-month period over which to complete the project, rather than the agreed-upon 4 weeks. The total level of effort would not have changed.

Furthermore, some unforeseen data quality issues emerged (with respect to the Port Dwelling time in Vancouver) and as a result, the deadline was pushed back, upon mutual agreement.

RESULTS AND RELEVANCE

The suggested scoring methodology provided TC's Economic Analysis and Research (EAR) group with a basis for implementing seasonality identification, and compensation methods. It is also known that the final report was circulated by EAR to a select group of academic and industry contacts.

It eventually made its way into the hands of Prof. Ata Khan, of the Faculty of Engineering and Design at Carleton University, who was impressed with the work and as a result enlisted CQADS's assistance for a study on the transportation of dangerous goods on behalf of the Nuclear Waste Management Organization.

PROJECT LOGISITCS

Timeline	10-May-13 to 12-Jun-13 (the original deadline of 07-Jun-13 was pushed back upon mutual agreement from both parties, given unexpected data issues)
Resources/Personnel	Patrick Boily, Ph.D. Managing Consultant, CQADS Project Lead / SME / Senior Analyst Yue Huang Consultant, CQADS Analyst (Time Series Analysis and Forecasting)
Total Effort Level	

250 hours (estimate)	**Boily**	**Huang**
Total:	125	125

Dollar Value	$4,424.73 (+ HST)
TC Project Authority	Alexander Gregory Economic Analyst Economic Analysis and Research 4900 Young Street North York, Ontario M2N 6A5 Canada 416 973-2444 alexander.gregory@tc.gc.ca