INNOVATIONS IN TRAVEL DEMAND FORECASTING FOR LAND-BASED PORTS OF ENTRY

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Introduction

Land-based ports of entry (POEs) are key elements of the transportation network connecting two countries. Bottlenecks, delay and congestion at POEs add supply chain costs (time, financial, environmental) and have potential negative impacts on economic growth. The relative importance of land-based POEs is often expressed through trade figures and vehicle movements, which are generally accepted transportation industry metrics. For example, in 2010 the top 6 Canada–United States POEs accounted for $237 billion in two-way truck-based trade and more than 7 million annual truck movements (Table 1).

Table 1. Top Six Canada – United States POEs (2010)

United States	Canada	Trade ($ B)	Two-Way Truck Traffic
Detroit	Windsor	91.7	2,620,000
Buffalo	Fort Erie	56.2	1,180,000
Port Huron	Sarnia	42.7	1,540,000
Champlain	Lacolle	18.4	620,000
Pembina	Emerson	14.3	370,000
Blaine	Surrey	13.9	700,000
TOTALS		237.2	7,030,000

Delays at POEs emanate from insufficient infrastructure when vehicle arrivals exceed processing capacity. Insofar as processing time is concerned, the main issue is the wide range and high variability of processing time rather than average measures of delay.

Significantly, most truck traffic is a component of just-in time supply chains. The direct cost of truck delays is estimated at $75 per hour (labour, fuel and opportunity cost). Wait times at POEs have been responsible for increasing production costs of a new vehicle in North America by C$800 in the past decade. Ford Motor Company claims delay costs of $200 per hour per truck at POE crossings. More significantly, a delayed shipment can prevent the delivery of key components and shut down an entire production line. For the automotive industry, estimated costs of production downtime range as high as $13,000 per minute (Anderson, 2012).

The bi-national *Beyond the Border* declaration (February 4, 2011) signed by President Obama and Prime Minister Harper provides the overarching policy framework for moving toward "a shared vision for perimeter security and economic competitiveness" in North America. The *Beyond the Border* declaration recognizes the critical importance of land-based POEs in their dual role of sovereign security and North American supply chain efficiency.

The *2012 Beyond the Border Implementation Report* notes that "efficient ports of entry are essential to the economic well-being of both Canada and the United States. An integrated bilateral approach to investment in infrastructure and technology is critical to maximizing the potential benefits of our shared economic space and to ensuring that we have the capacity to support the current and future volumes of commercial and passenger traffic that are critical to economic growth and job creation." A major output of the Beyond the Border process is to develop a five-year joint Border Infrastructure Investment Plan (BIIP) covering coordinated upgrades such as customs plaza replacement and redevelopment, additional primary and secondary lanes and booths, and expanded or new connecting roads and highway interchanges (Moens and Gabler, 2012b).

In a decision-making environment that is increasingly influenced by factors related to fiscal restraint, the competition for scarce resources to improve transportation infrastructure requires appropriate merit based justifications to illustrate the case for making multi-million dollar strategic investments. Furthermore, in the case of POE infrastructure delivery, the bi-national and multi-agency decision making context requires a lead time of 6 to 10 years to deliver a coordinated infrastructure solution involving as many as 6 federal, state and provincial agencies. When planning for projects that must meet the needs for 20+ years and which can take over a decade to implement, defensible forecasts of traffic projections are vital to justify proposed investments.

The applicability of a new forecasting methodology for POEs as articulated in this paper is that, once developed and fully operational, the methodology can be adapted to any major POE. In this regard, there are 120 land-based Canada–United States POEs and 44 land-based Mexico–United States POEs. In practical terms, the top 20 POEs along the Canada–United States and Mexico–United States could benefit from the application of this methodology.

A common economic metric in justifying infrastructure projects is the benefit-cost analysis approach, based on ratio of user benefits to capital costs over at a minimum of 20 years. A predominant metric is the reduction in wait times on a per vehicle basis. Therefore, any analysis requires vehicle arrival forecasts at a granular level down to the hour for each day of every year out to the planning horizon (typically 20 years).

The purpose of this paper is to illustrate the importance of developing precision forecasts of hourly vehicle arrivals (by vehicle category) as a basis for evaluating, planning and constructing merit-based infrastructure improvements at a land-based POE. A recently completed conceptual planning study for the Pembina–Emerson POE (2013) was used as the case study for this paper. This paper also relates to the companion paper entitled "A Level of Service Framework for Evaluating Port of Entry Performance" presented at this CTRF conference.

Methodology Integration

The Pembina–Emerson POE study is referenced as a case study in this paper to illustrate the critical importance of developing accurate hourly forecasts of vehicle arrivals at POEs. The accuracy of the forecast inputs drives the precision of the demand-capacity analysis and simulation models that are used as a basis for formulating various POE improvement scenarios. Forecast inputs are used to calibrate traffic simulation models to determine critical infrastructure requirements, based on 30th highest hour design, as well as generate output for an innovative Level-of-Service (LOS) framework for evaluating POE performance. Manitoba Infrastructure and Transportation (MIT) developed the forecast methodology and LOS framework for the Pembina–Emerson study. Figure 1 illustrates the relationship between forecast development, simulation models and LOS analysis.

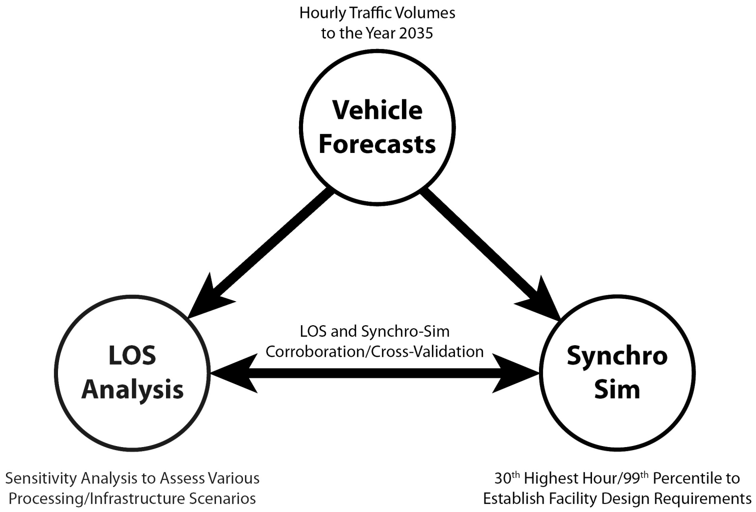

Figure 1. Relationship between Vehicle Forecasts. Level-of-Service and Micro-Simulation Modeling

Inadequacy of Contemporary Demand Forecasting for POE Applications

For the Pembina–Emerson study, demand forecasts to 2035 by direction and vehicle type (autos, trucks) were required. The standard approach is to use average annual daily traffic (AADT) multiplied by several sets of expansion factors for each of the two vehicle classes to calculate the desired level of granularity (monthly, weekly, daily, hourly). The technique is described in the 2010 Highway Capacity Manual (HCM), the 2005 National Cooperative Highway Research Program (NCHRP) Report 538, and the 2010 Institute of Transportation Engineers (ITE) Transportation Planning Handbook.

For both autos and trucks, expansion factors were developed from vehicle count estimates at Manitoba Highway permanent counting station 31, two kilometres north of the Pembina–Emerson POE as a proxy for the POE. Figure 2 shows the AADT temporal distribution for both total traffic and the proportion of truck traffic at station 31.

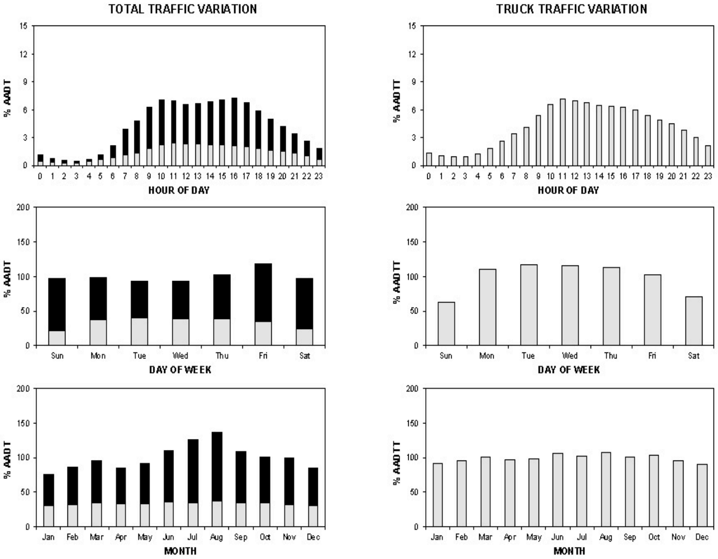

Figure 2. Pembina–Emerson POE
AADT Expansion Factors

An example best illustrates how the HCM-based expansion factors are applied using Station 31 data to calculate northbound auto traffic on a Monday in February 2011 at 6:00 pm:

2011 AADT $_{\text{Northbound}}$ = 1,650
Percent Autos (PA) = 65%
February Expansion Factor (FEF) $_{\text{autos}}$= 62.9%
Monday Expansion Factor (MEF) $_{\text{autos}}$ = 105%
Hourly Expansion Factor (HEF) $_{\text{6:00 pm}}$ = 6%

Hourly Auto Traffic = AADT x PA x FEF x MEF x HEF

This example illustrates that 44 autos per hour are forecast in the northbound direction for this year, month, day and hour. While this forecast distribution approach seems logical, it failed to replicate any excessive delays or queue lengths that would trigger infrastructure re-design. Furthermore, these HCM-based results contradicted field observations where peak period delays for a similar date were in excess of 2 hours with queue lengths over a mile.

As such, it was determined that the HCM-based approach for developing hourly forecast data for the Pembina–Emerson POE did not have any validity. The next two sections summarize an alternative approach developed by MIT for generating hourly forecast data (both autos and trucks), which were validated by ground truth observations and historical data. Bus activity was removed from the forecasts at Pembina–Emerson because it only accounts for 0.02% of total traffic.

Aggregate Auto Volume Forecasting

Recent studies in travel demand forecasting (Anderson 2006, 2012b) attempt to link land use activity, exchange rates, fuel prices, demographics, traveler choice behaviour and other characteristics as parameters in trip generation forecasting. Although these techniques provide insights on how trips are generated, they are static models based on trip generating factors for a defined region and are not directly applicable to regions as large as continental North America.

Rather, standard regression analysis for auto trips that correlates to population growth was used to generate future AADT, with high-low projections at 1% each side of the average. For Pembina–Emerson auto traffic growth has been steady over the past 15 years at 2.6%. Bi-direction growth projections with high-low ranges are shown in Figure 3.

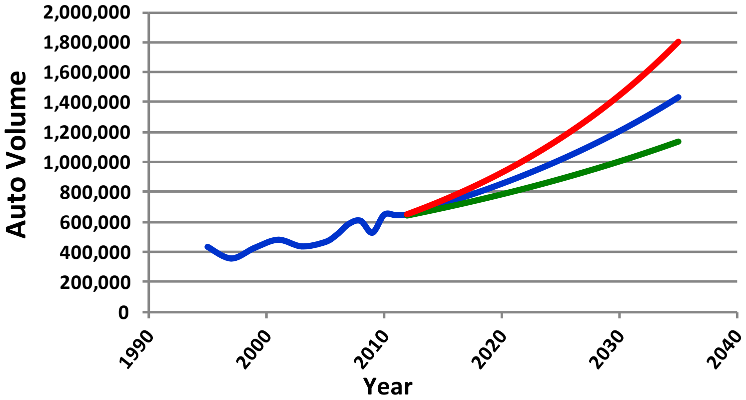

Figure 3. Pembina-Emerson Port of Entry Bi-Directional Auto Volume Growth with High-Low Ranges

Aggregate Truck Volume Forecasts

Truck forecasts were based on forecast commodity figures for the Pembina–Emerson POE extracted from the 2009 National Commodity and Trade Flow Survey commissioned by Transport Canada. A total of 30 commodity groups were forecast in the study based on a North American production-consumption model. MIT obtained the southbound and northbound annual commodity tonnages for the Pembina–Emerson POE and converted these data to bi-direction annual truck flows using techniques in appendix A and B of NCHRP report 538, namely:

- Annual truck loads by commodity group estimated according to net cargo weights by GVW,
- GVW of I-29 and I-94 in U.S. used to determine weighted average GVW,
- Net cargo weights calculated by subtracting truck tare from GVW used in commodity industry,

- Empty backhauls by percent and direction were used to calibrate aggregate truck flows.

Bi-directional aggregate truck traffic future forecasts were calibrated by “backward” forecasting into historical data and using a *Microsoft Solver*™ model to calculate the direction percent aggregate annual growth. The aggregate forecasted truck traffic is a combination of loaded and empty moves by direction, as shown in Figure 4.

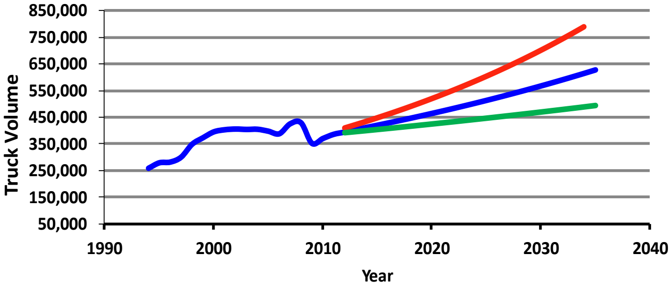

Figure 4. Pembina-Emerson POE Bi-Directional Truck Volume Growth with High-Low Ranges

Pattern Recognition in Revising Expansion Factors

For the Pembina–Emerson study, historical hourly vehicle arrival rates for a 5-year historical period were obtained from US Customs and Border Protection (CBP) for the southbound direction of travel and Canada Border Services Agency (CBSA) for the northbound direction of travel. This consisted of Primary Inspection Lane (PIL) booth counts (autos and trucks) by each agency for each hour of every day of the year.

The data revealed POE arrival rates with wide ranges, not unlike AADT patterns at permanent counting stations. Figure 5 illustrates southbound data that reflect these arrival patterns. However, use of general expansion factors as prescribed in the HCM has the effect of washing out the peaking patterns that occur when delays and queue lengths reach their maximum.

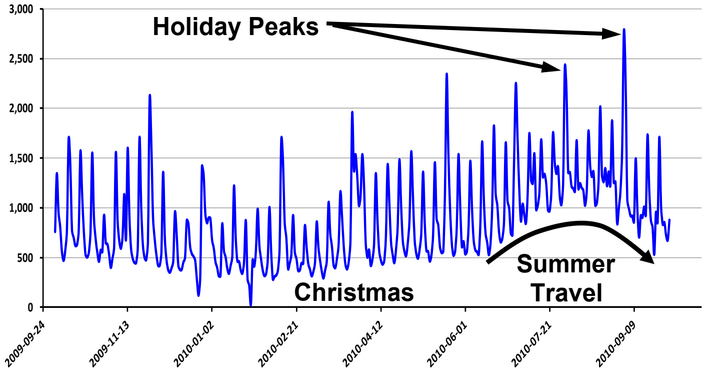

Figure 5. Pembina–Emerson Sample
Southbound Auto Arrival Pattern

Determining the magnitude and pattern recognition characteristics in auto and truck expansion factors was a crucial step in producing more credible forecasts to properly analyze the impact in traffic growth on infrastructure requirements and facility re-design. Developing custom expansion factors requires expert interpretation of historical arrivals data to understand the patterns and the unique peaking characteristics associated with each POE.

Activity-based trip generation models are not suitable as these involved too many parameters that, when combined, decrease the reliability of results and requires maintaining an information system on all facets for large regions. The underlying vehicle arrival patterns at the Pembina–Emerson POE revealed several unique characteristics of auto and truck traffic, namely:

- Both southbound and northbound auto and truck traffic had very different hourly arrivals by time of day and by day of week. For example, southbound autos on a Friday had a narrow band between 4:00 pm and 7:00 pm, whereas on Sundays, the northbound auto peak was between 3:00 pm to 10:00 pm. This is reflective of weekend travelers from Manitoba to North Dakota departing after work on Fridays and returning under a more leisurely pace on Sundays.

- There was no uniformity in weekly arrival patterns by direction, nor within the two main vehicle classes. Weekly patterns varied not only within each month, but more so around cultural events such as religious holidays and civic holidays, when schools ended, for example. The week after schools let out tended to double normal values as families began vacations. Weekly averages mask these occurrences.
- Holidays such as Victoria Day and Black Friday had peaking patterns that were quadruple normal arrivals. Christmas Day for example, was consistent at about 1% or less of normal. In one year, only 5 vehicles southbound were recorded for the day as compared to a daily average of 550.
- The Easter period, which fluctuates between March and April, can often occur during the school spring break period and create a pattern of arrivals that varies year by year. This requires several sets of expansion factors to account for the proximity of these events.
- Holidays with fixed dates that move through the days of the week had different expansion values according to the day of the week. When the holiday occurred on a Friday or a Monday, producing a three-day weekend, expansion values were doubled or more over normal.

When it became apparent that travel behaviour patterns according to the aforementioned observations occurred with regularity, the following approach and rules in developing custom expansion factors and forecasts were formulated and applied:

- There was sufficient information to develop custom factors for *each individual day of the year*, that resulted in a 365 x 7 array of expansion factors, and,
- These custom expansion factors were separated by *auto and truck, by direction*, and
- Special expansion factors were developed for both vehicle classes, *for each Canadian and American holiday*, by day of the week, and,

- Hourly expansion factors were developed for *each hour for each day by direction*.

Tables 2, 3 and 4 shows samples of the expansion factor tables produced by MIT for vehicle arrivals: Table 2 is for general days of the year that are not influenced by holidays, Table 3 is special values to cover actual holidays and the days adjacent, and Table 4 is hourly factors for each day of the week. These are remarkably consistent through the 5 years of data, particularly for trucks, with only slight variations in magnitude.

Table 2: Southbound Autos (daily expansion factors)

Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
01-Jan	1.14	0.57	0.48	0.76	0.86	0.57	1.33
02-Jan	1.33	0.67	0.57	0.67	1.00	0.57	1.33
03-Jan	1.43	0.57	0.48	0.48	1.71	0.52	0.62
04-Jan	1.43	0.57	0.48	0.86	1.71	0.52	0.62
05-Jan	1.43	0.43	0.33	0.67	1.71	0.52	1.33
06-Jan	1.24	0.43	0.33	0.67	1.71	0.52	1.24
07-Jan	1.24	0.43	0.33	0.67	1.62	0.48	1.14
08-Jan	0.51	0.44	0.49	0.65	1.20	0.73	0.60
09-Jan	0.51	0.44	0.49	0.65	1.20	0.73	0.60
10-Jan	0.51	0.44	0.49	0.65	1.20	0.73	0.60
11-Jan	0.51	0.44	0.49	0.65	1.20	0.73	0.60

Table 3: Southbound Autos (holiday expansion factors)

Holiday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Louis Riel Day	0.98	0.49	0.59	0.99	2.16	2.11	1.35
Spring Break (week 1)	1.54	1.36	1.47	1.82	2.48	2.11	1.91
Spring Break (Week 2)	1.54	1.36	1.47	1.82	1.84	0.83	0.64
Easter	0.52	1.00	1.00	1.00	0.71	0.52	0.44
Victoria Day	0.82	1.00	1.00	1.33	2.95	2.11	1.32
July 1st	1.19	1.24	1.62	2.61	3.09	1.51	1.17
August Long	1.50	1.00	1.00	1.00	2.95	2.61	1.60
Labour Day	1.15	1.00	1.00	2.14	3.56	2.67	1.43
Thanksgiving	1.02	1.00	1.00	1.24	2.52	2.06	1.30
Rememberance Day	1.09	1.19	1.19	3.18	3.56	1.19	0.81
Black Friday	1.00	1.00	1.00	2.96	1.85	0.90	0.77

Table 4: Southbound Autos (sample of hourly factors)

Hour	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
1	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%
2	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%
3	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%
4	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%
5	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%
6	0.75%	0.75%	0.75%	0.75%	0.75%	1.50%	0.75%
7	1.00%	1.00%	1.00%	1.00%	1.00%	3.50%	1.00%
8	1.50%	1.50%	1.50%	1.50%	1.50%	5.50%	1.50%
9	3.00%	3.00%	3.00%	3.00%	3.00%	7.50%	3.00%
10	5.50%	5.50%	5.50%	5.50%	4.00%	11.50%	5.50%

Figure 6 shows a simplified approach to calculating hourly forecasts, taking into account the day of the year, whether it is a holiday and the hourly factor. The accuracy is improved as factors for each day of the year are produced, eliminating the monthly, weekly and any seasonal trends. The only special condition is the holiday factor. The HCM-based formula in *Inadequacy of Contemporary Demand Forecasting for POE Applications* for the northbound hourly auto example is thereby revised as follows:

(HCM) Hourly Auto Traffic = AADT x PA x FEF x MEF x HEF

(MIT) Hourly Auto Traffic = AADT x PA x DEF x HEF

The daily expansion factors (DEF) for each day of the year, as shown in Table 2, replaces the monthly and weekly factors. While the HEF remains the same in the equation, the detailed border arrival counts were used to improve the precision of factors.

Comparison of HCM versus MIT Forecast Methods

The MIT forecast methodology proved to be superior to the standard HCM approach for several reasons. Table 5 provides a comparison between the HCM methodology example used in *Inadequacy of Contemporary Demand Forecasting for POE Applications* and the MIT methodology developed for the Pembina–Emerson POE study as presented in *Pattern Recognition in Revising Expansion Factors*. The HCM methodology produced a result of 44 autos per hour northbound on Monday, February 18, 2011, at 6:00 pm (Riel Day provincial holiday). The methodology developed by MIT predicted a value of 252 auto arrivals for the same day/time with the actual count being 210 autos. As such, the HCM methodology understated actual arrivals by 477% whereas the MIT methodology reflected a 20% variance from actual counts. Clearly, the MIT methodology more precisely reflected observed arrivals.

Table 5: Auto Arrival Forecasting Method Comparison

Northbound Autos – Monday, Feb. 18, 2011 6:00 pm

Auto Arrivals	Forecast Method
44	2010 HCM, NCHRP 538 (Original)
252	MIT Methodology
210	Actual Counts from Border Data

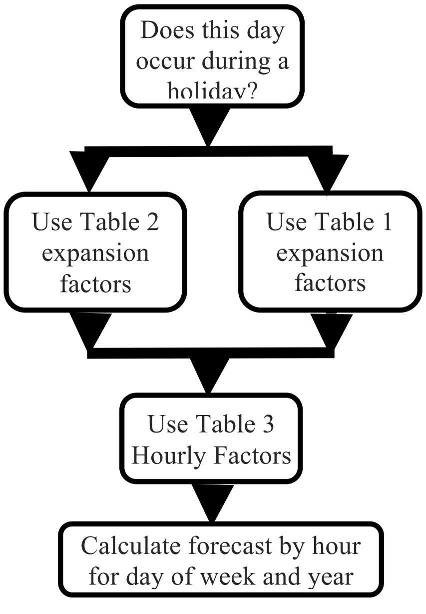

Figure 6. Decision Flowchart for Algorithm Used to Generate Vehicle Forecasts at Pembina–Emerson POE

Further validation of the MIT methodology occurred in 2012 when actual arrival data for the first quarter were obtained. These data were used to assess the accuracy of the forecasts for the same period to determine the variance between forecast values and observed arrivals. Figure 7 illustrates HCM forecast, MIT forecast and actual data for the first quarter of 2012. The HCM forecast line shows how the general average method fails to capture arrival peaks. The MIT forecast methodology closely approximated the observed oscillations of vehicle arrivals and was able to predict the pattern of vehicle arrivals during regular weekly periods as well as the more unique holiday peaking.

The MIT methodology still requires some refinement to capture all the peaking anomalies. The one period of the year subject to further refinement is between Christmas and New Year, as evidenced in figure 7. The historical data showed great inconsistency from year to year during this period. There were some very weak patterns that were observed, for example if New Year's Day fell on a weekday as opposed to a weekend. The same observation would apply to Christmas day. Vehicle flows at the POE during the interim period showed a weak correlation to when both dates fell on weekend dates.

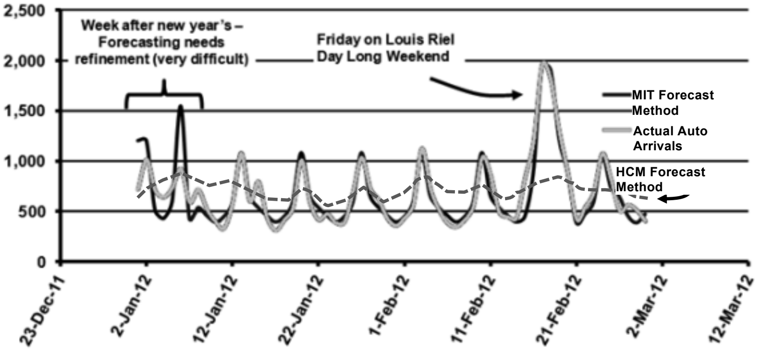

Figure 7. Comparison of Forecast Methods to Actual 2012 Southbound Auto Arrivals

However, these minor inconsistencies do not skew simulation results, LOS analysis, infrastructure assessments or trigger points for improvements.

Conclusions

The importance of an accurate traffic forecasting methodology, as described in this paper, has high-level policy implications regarding POE infrastructure investment decisions. Sound forecast data are of paramount importance in any POE planning process given that the cost of recommended infrastructure improvements are typically quite high. For example, all Detroit River International Crossing (DRIC) components are estimated to exceed $2 billion.

In the Pembina–Emerson study, full build-out for all elements of the recommended alternative is expected to be in the order of $60 million. However, the southbound and northbound improvements can become operational with an investment closer to $20 million. Furthermore, an investment of $20 million will return the full $355 million in benefits southbound and $222 million in benefits northbound attributed to reduced fuel consumption and emission reductions to the year 2035. Although a $20 million investment for a top 5 POE seems reasonable, particularly when those costs are distributed between four implementing agencies and the benefits are substantial, competition for merit-based funding in a fiscally restrained decision-making environment remains a reality.

As such, highly accurate forecasting for POEs on an hourly level allows for greater levels of confidence in applying the methodologies that are necessary to develop the engineering design (30th highest hour), evaluate POE performance (LOS analysis) and justify merit-based investments. Furthermore, without highly reliable forecasts on an hourly level, it was demonstrated that traffic simulation models were incapable of capturing historical peaking patterns and producing meaningful results to generate appropriate design alternatives. In applying the MIT forecast methodology to other POEs, accurate historical, port-specific, hourly data is a prerequisite for customizing expansion factors to the unique characteristics of that port.

In view of these considerations the costs to government of investing in the ongoing maintenance of effective databases necessary to undertake appropriate analysis is also a long-term consideration.

Acknowledgments

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Gannett Fleming conducted simulation modelling for the Pembina–Emerson POE and prepared the final study report.

CBSA/CBP provided Pembina–Emerson POE historical arrival data.

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