A LEVEL OF SERVICE FRAMEWORK FOR EVALUATING LAND-BASED PORT OF ENTRY PERFORMANCE

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1. 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) and have potential negative impacts on economic growth and the environment. 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 six 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

When describing the operational deficiencies of a specific POE, historical performance measures such as delay or wait time and queue lengths are often referenced. These negative performance measures are often anecdotal, random, non-standardized or difficult to quantify. Ongoing discussions and initiatives at the Transportation Border Working Group (TBWG is a bi-national forum for coordinating Canada-United States border issues) and Joint Working Committee

(JWC is a bi-national forum for coordinating Mexico-United States border issues) underscore this point.

Furthermore, measurements of delay and congestion by themselves are insufficient to support justifications for extensive capital improvements to POE infrastructure. As such, appropriate planning methodologies are essential for developing and evaluating proposed POE infrastructure improvements as well as describing service level improvements. However, the development and application of methodologies to assess the delay and congestion implications of port improvement scenarios have not kept pace with the growing significance of these key land-based transportation assets.

In a recently completed study of the Pembina-Emerson POE (2013), Manitoba Infrastructure and Transportation (MIT) took a leadership role in developing an innovative measure of POE performance based on the Level-of-Service (LOS) concept utilized in the Highway Capacity Manual (HCM).

The LOS framework and corresponding algorithms that were developed by MIT for the Pembina-Emerson study can be applied to any POE to assess port throughput. The LOS framework for POEs provides a useful policy tool for evaluating multiple combinations of processing times, staffing levels or infrastructure improvement scenarios that orthodox methodologies have not captured.

Combining the LOS framework (a policy-level approach) with 30th highest hour design (an engineering infrastructure design approach) provides transportation policy makers, planners and engineers with better decision-making tools to assess infrastructure design issues, phasing considerations and service level improvements for a proposed POE concept.

The purpose of this paper is to illustrate the value of adapting the LOS concepts found in the HCM to evaluate POE performance. The recently completed Pembina-Emerson study provides examples of how the LOS framework is applied to a POE planning context. The significance of the LOS framework and corresponding algorithm derived output is that they can provide easily interpreted annualized data for every hour of every year (8,760 hours in a typical year) over a 20+ year planning period and allocate these values to various LOS categories.

From a policy-level perspective, this output is especially well suited to describing POE service levels for pre and post improvement scenarios. The LOS framework and analysis complements the engineering design approach (30th highest hour) by providing easily interpreted longitudinal output of service level offerings for a variety of port scenarios which can be readily understood by elected officials, stakeholders and the public.

This paper is the companion paper to "Innovations in Travel Demand Forecasting for Land-Based Port's of Entry" presented at this CTRF conference.

2. Methodology Integration

Figure 1 illustrates the relationship between forecast development, traffic simulation models and the LOS framework and analysis as developed by MIT for the Pembina-Emerson POE study. (Ref. 1)

The applicability of the LOS methodology in the POE context is such that, once developed and fully operational, the model can be adapted to evaluate any major POE with significant traffic volumes. In this regard, there are 120 land-based Canada–United States POEs and 44 land-based Mexico–United States POEs that the methodology could be applied. In practical terms, the top 20 POE along the Canada–United States and Mexico–United States could benefit the most from the application of this methodology.

3. Level of Service Concept and Framework

The LOS framework for land-based POEs is derived from concepts in the HCM for uninterrupted (freeway conditions) and interrupted (intersection conditions) flows. (Ref. 2, 3, 4, 5)

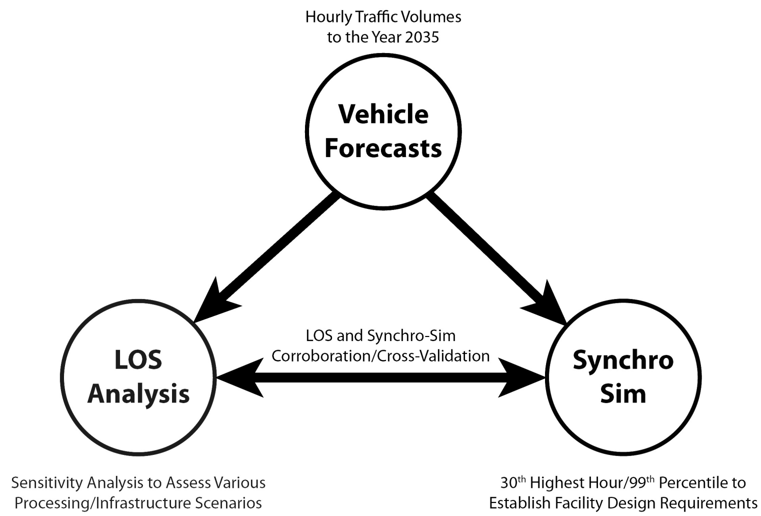

Figure 1. Relationship between Vehicle Forecasts. Level-of-Service and Micro-Simulation Modeling

Table 2 illustrates the LOS framework developed by MIT for POE applications. The LOS framework utilizes standard A-F service level categories found in other HCM applications. Generally speaking, service levels A and B reflect no delay or minimal delay conditions, C and D short to moderate delays and E and F significant to severe delays. Three criteria were utilized to determine service level conditions, namely:

- Volume to Capacity Ratio: Volumes (arrival rates) were developed utilizing the forecast methodology outlined in the companion paper entitled, "Innovations in Travel Demand Forecasting for Land-Based POEs". Maximum theoretical PIL booth processing capacity was used as the proxy for POE capacity. Theoretical processing capacity, another Pembina-Emerson study innovation, was derived using an assumption for processing time per vehicle to obtain hourly POE maximum throughput.

  (vph processed per PIL) x (PIL positions) = Max Capacity

Therefore if a 2 minute per vehicle processing time was used for a 10 PIL booth configuration the maximum theoretical processing capacity of the POE would be 300 vehicles per hour in a specified direction of travel. V/C ratios were calibrated with output from the simulation model.

- Magnitude of Delay: Defined as the delay to individual vehicles and calibrated with the simulation model
- Duration of Delay: Defined as the duration of the vehicle queue and calibrated with the simulation model

Table 2. Level of Service Framework for POEs

Level of Service	Flow Conditions	LOS Description	Primary Trigger for Capacity Improvements	Secondary Measures to Be Considered	
			Magnitude of Average Vehicle Delay (minutes)	Duration of the Delay Period (hours)	v/c Ratio
A		Free flow conditions entering PIL plaza, unimpeded manoeuvrability within PIL plaza, queuing limited to a few vehicles in each PIL, no delay, driver comfort levels are very high. **No Delays**	<5 min	negligible	< 0.9
B		Near free flow conditions entering PIL plaza, drivers experience minor restrictions when manoeuvring vehicles within PIL plaza, queuing within PIL plaza only, minimal delay, driver comfort levels are high. **Minimal Delays**	≧ 5 min < 15 min	negligible	0.9-1.2
C		Manoeuvring within PIL plaza becomes constrained, queuing extends beyond PIL plaza onto highway facility and begins to affect lane assignment strategies, moderate delay, driver comfort levels are acceptable. **Short Delays**	≧ 15 min ≦ 20 min	< 1 hr	1.2-1.4
D		Queuing extends upstream on highway facility and begins to affect manoeuvring related to both advance notification and lane assignment strategies, moderate delay, drivers may experience poor levels of comfort. **Moderate Delays**	>20 min ≦25 min	1-2 hr	1.4-1.6
E		Queuing extends significantly upstream on highway facility, queue length limits effectiveness of advance notification and lane assignment strategies, significant delay, very poor driver comfort levels. **Significant Delays**	>25 min ≦45 min	> 2 hr	1.6-2.5
F		Queuing extends significantly upstream on highway facility, queue length limits effectiveness of advance notification and lane assignment strategies, severe delay, extremely poor driver comfort levels. **Severe Delays**	>45 min	> 2 hr	>2.5

4. Development of Level of Service Algorithms

Figure 2 illustrates the queuing model that was used to develop algorithms for converting hourly vehicle arrival data (forecasts) into various LOS categories. The various phases and inflection points in the model were calibrated with the LOS framework in Table 2 and are briefly described as follows:

- State 1: (LOS A and B) Unsaturated state where there are only minor delays and no queues. Up to point a”, vehicle arrival rates are less than maximum theoretical processing capacity (capacity).
- State 2: (LOS C and D) Build-up state where vehicle arrival rates exceed capacity beyond point a” and minor to moderate queuing occurs.
- State 3: (LOS E and F) Saturated state where combined vehicle arrival rates/queues beyond point b” exceed capacity and moderate to severe queuing occurs.
- State 4: (LOS A to F) Dissipation state where vehicle arrival rates/queues peak above capacity at point c” and then decline to below capacity at point d”. Queue length is the sum of vehicle arrivals over capacity from point a” to point c”. Between point b” and c” the peak arrival period ends. Between point c” and d”, arriving vehicles are still delayed because of a queue, but the average wait time is declining as the queue begins to dissipate. As the system moves beyond point d”, the combined vehicle arrival rates/queues are less than capacity and the system returns to the unsaturated state.

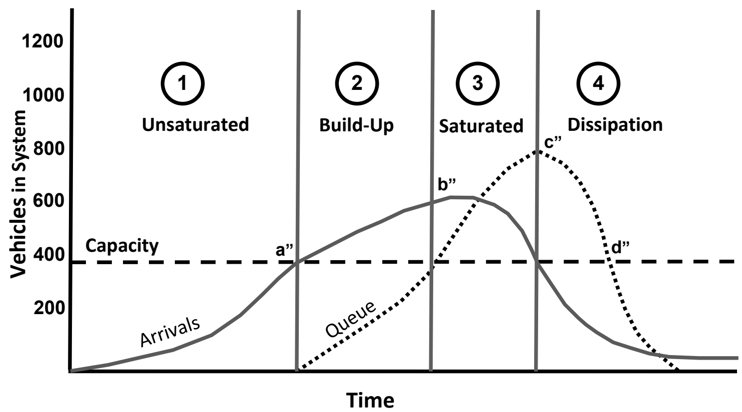

Figure 2. Vehicle arrival and queuing model used to develop wait time and LOS performance

5. Interpreting Level of Service Output Tables

Two examples of LOS output from the Pembina-Emerson study are provided to illustrate the descriptive capabilities of this methodology.

Example 1: Multi-Dimensional/Multi-Variant Characteristics

Tables 3 and 4 illustrate the LOS hourly buckets (total hours/ percentage hours) for two processing times (1.50 min/1.75 min) and three PIL (6, 8 and 10) scenarios for 2015 and 2030 in the northbound direction of travel at the Pembina-Emerson POE. The LOS time intervals for service levels A to F are based on the calibrations in Table 2 (duration: delay to individual vehicles/magnitude: duration of queue). The algorithms allow for time interval calibrations that can be customized to reflect a particular LOS policy. The algorithms also allow for PIL configuration (infrastructure or staffing levels) and processing time parameters to be customized to reflect a wide array and combination of service offering scenarios. In the case of processing time, blended processing rates based on the ratio of trusted travellers (NEXUS) or trusted traders (FAST) to standard documentation users could be developed to match the characteristics at a specific POE.

The resultant tabular output reflects a multi-dimensional analysis in a two-dimensional format. (x-axis: PIL infrastructure or staffing, y-axis: Processing time and z-axis: LOS policy) In this regard, the impact of adjusting either PIL capacity or processing time can be evaluated within the context of a pre-set LOS policy.

Tables 3 and 4 illustrate how PIL capacity and processing time variables can be used to evaluate pre-set LOS policy by indicating how many hours will fall into each LOS "bucket". For any given forecast year it is possible to quantify the impact of service level changes on service level policy by interpreting the LOS output tables. This policy-driven approach is superior to methods that merely attempt to ascertain average wait times for queued vehicles.

Table 3. Pembina-Emerson POE (Northbound 2015)

		2015					
Number of PILs		6		8		10	
Time	LOS	Total Hours	% Hours	Total Hours	% Hours	Total Hours	% Hours
1.75 min 105 sec	A	8,473	96.7%	8,735	99.7%	8,756	100.0%
	B	36	0.4%	4	0.0%	1	0.0%
	C	1	0.0%	1	0.0%	0	0.0%
	D	23	0.3%	0	0.0%	1	0.0%
	E	192	2.2%	20	0.2%	2	0.0%
	F	35	0.4%	0	0.0%	0	0.0%
1.50 min 90 sec	A	8,670	99.0%	8,749	99.9%	8,760	100.0%
	B	27	0.3%	1	0.0%	0	0.0%
	C	0	0.0%	0	0.0%	0	0.0%
	D	7	0.1%	1	0.0%	0	0.0%
	E	40	0.5%	8	0.1%	0	0.0%
	F	16	0.2%	1	0.0%	0	0.0%

In Table 3 (2015 traffic volumes) 8,473 hours will fall in the LOS A category (96.7% of all 8,760 annual hours) with a 6 PIL configuration and a 1.75 mpv (minutes per vehicle) processing rate. The remaining 287 hours (2.3%) will fall in LOS categories B through E.

In Table 4 (2030 traffic volumes) only 6,598 hours will fall in the LOS A category (75.3% of all annual hours) with a 6 PIL configuration and a 1.75 mpv (minutes per vehicle) processing rate due to the projected increase in traffic. The remaining 2,162 hours (24.7%) will fall in LOS categories B through E.

Table 4. Pembina-Emerson POE (Northbound 2030)

		2030					
Number of PILs		6		8		10	
Time	LOS	Total Hours	% Hours	Total Hours	% Hours	Total Hours	% Hours
1.75 min 105 sec	A	6,598	75.3%	7,859	89.7%	8,509	97.1%
	B	110	1.3%	78	0.9%	37	0.4%
	C	18	0.2%	15	0.2%	5	0.1%
	D	29	0.3%	41	0.5%	4	0.0%
	E	876	10.0%	539	6.2%	174	2.0%
	F	1,129	12.9%	228	2.6%	31	0.4%
1.50 min 90 sec	A	7,343	83.8%	8,358	95.4%	8,687	99.2%
	B	88	1.0%	37	0.4%	8	0.1%
	C	6	0.1%	2	0.0%	1	0.0%
	D	32	0.4%	16	0.2%	2	0.0%
	E	711	8.1%	284	3.2%	52	0.6%
	F	580	6.6%	63	0.7%	10	0.1%

Example 2: Pre and Post Improvement Analysis

Tables 5 and 6 illustrate LOS hourly buckets for pre and post improvement scenarios for the northbound direction of travel at the Pembina-Emerson POE. Table 5 illustrates that for the northbound direction of travel, LOS begins to significantly decay by 2025 with the current infrastructure (6 PILS) based on the projected traffic growth. A comparison of the output for 2025 in Table 5 (pre improvement scenario of 6 PILS) and Table 6 (post improvement scenario of 9 PILS) demonstrates that by adding 3 additional PILs (a 1.25 mpv processing rate was used for both scenarios) a significant improvement in LOS occurs out to 2035 over the pre improvement conditions.

Table 5. Pre Improvement Scenario
(6 PILS Northbound 2015-2035)

		2015		2020		2025		2030		2035	
Max Time (minutes)	LOS	Total Hours	% Hours	Total Hours	% Hours	Total Hours	% Hours	Total Hours	% Hours	Total Hours	% Hours
5	A	8,742	99.8%	8,704	99.1%	8,502	97.1%	8,024	91.6%	7,475	85.3%
15	B	1	0.0%	13	0.1%	31	0.4%	107	1.2%	73	0.8%
20	C	1	0.0%	1	0.0%	12	0.1%	11	0.1%	11	0.1%
25	D	1	0.0%	2	0.0%	168 / 15	0.2%	42	0.5%	31	0.4%
45	E	15	0.2%	55	0.6%	82 / 16[illegible]	1.9%	416	4.7%	679	7.8%
>45	F	0	0.0%	9	0.1%	32	0.4%	160	1.8%	491	5.6%

Table 6. Post Improvement Scenario
(9 PILS Northbound 2015-2035)

		2015		2020		2025		2030		2035	
Max Time (minutes)	LOS	Total Hours	% Hours	Total Hours	% Hours	Total Hours	% Hours	Total Hours	% Hours	Total Hours	% Hours
5	A	8,760	100.0%	8,780	100.0%	8,745	99.8%	8,696	99.3%	8,573	97.9%
15	B	0	0.0%	2	0.0%	3	0.0%	12	0.1%	18	0.2%
20	C	0	0.0%	0	0.0%	1	0.0%	1	0.0%	5	0.1%
25	D	0	0.0%	0	0.0%	0	0.0%	6	0.1%	11	0.1%
45	E	0	0.0%	3	0.0%	12	0.1%	40	0.5%	131	1.5%
>45	F	0	0.0%	0	0.0%	0	0.0%	7	0.1%	23	0.3%

6. Comparing 30th Highest Hour Design with Level of Service

The 30th highest hour design is an engineering methodology used to establish and test a specific facility design. In the case of a POE, the 30th hour design can be used to establish the number of PIL positions that are necessary to adequately meet demand up to the planning horizon year. The 30th highest hour is calculated by arranging the hourly volumes for an entire year (8,760 total annual hours) in descending order and then identifying the value for the 30th highest hour to be used as a basis for developing and testing the engineering design. A design based on the 30th highest hour is theoretically capable of providing adequate capacity for most of the demand which occurs throughout the year. As a percentile, the 30th hour design is expected to accommodate traffic during 99.7 % of the hours in a year.

However, this approach does not explain the annual 8,760 hour demand profile for a transportation facility insofar as there is no reference to the specific magnitude of the 29 hours above or 8,730 hours below the 30th highest hour. Furthermore, a 30th highest hour design is based on a single hourly volume and does not capture the cumulative impacts of consecutive high volume hours that can occur on the shoulders of the 30th highest hour. Given that POE peaks are typically of much longer duration (4 to 6 hours in some cases) than urban AM or PM commuter peak periods, the 30th highest hour could potentially understate a design if several high volume hours occur consecutively over an extended period of time during the day.

Figure 3 illustrates three scenarios that reflect the aforementioned limitations in using the 30th highest hour design to explain annual demand profiles at a POE. Scenario A reflects a situation where the 29 hours above the 30th hour are significantly higher than the 30th hour. Scenario B illustrates a situation where a large number of hourly volumes above and below the 30th highest hour are clustered. Scenario C represents a situation where the annual demand profile is rather flat at the high volume end for extended periods. In each scenario there is no means available to test the cumulative effect of high volumes that potentially occur during consecutive hours on the shoulders of the 30th hour design.

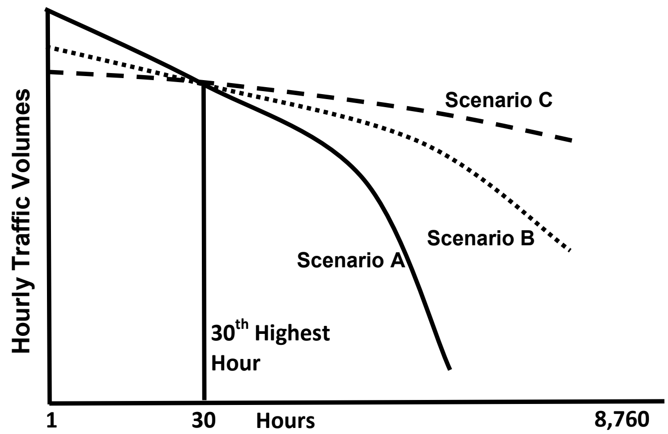

Figure 3. 30th Highest Hour Scenarios

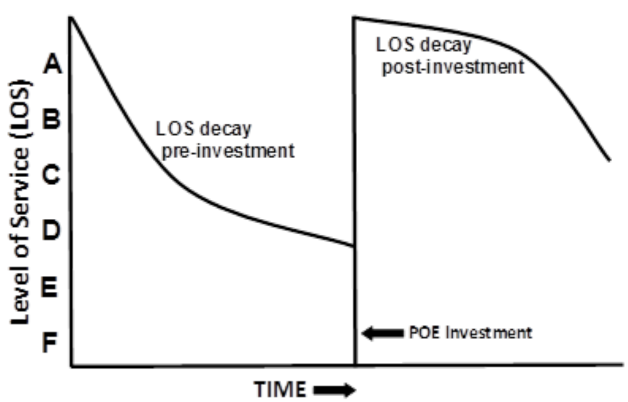

Figure 4. LOS Decay (Pre and Post Investment)

Figure 4 is a conceptual representation of how the LOS concept can be used to illustrate decay or improvement in LOS attributed to changes in infrastructure, staffing or processing times in conjunction with any projected vehicle demand scenario. In Figure 4 a blended LOS trend line is used to conceptually illustrate this principle. The actual LOS output tables would be used to evaluate specific pre and post scenarios.

Integrating 30th highest hour design with LOS principles requires further calibration. Given that the LOS framework developed for POE applications reflects applied research developed during a time bound planning project (Pembina-Emerson study) further case studies may be necessary to corroborate the methodology. Additionally, correlation of the LOS framework with 30th highest hour design outputs should involve further evaluation of the equations and inputs used in various simulation models.

7. Conclusions

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 strategic investments. Furthermore, in the case of POE infrastructure delivery, the bi-national and multi-agency decision making context requires a lead time of between 6 to 10 years to deliver a coordinated infrastructure solution involving as many as 6 federal, state and provincial agencies.

When planning for projects in a merit-based environment that must meet the needs for 20+ years and can take over a decade to implement, it is crucial to have a policy level tool that can not only help justify proposed POE investments but also clearly illustrate comparative longitudinal service level data for both pre and post improvement scenarios.

The benefits of an LOS framework and analysis for evaluating POE performance are numerous and include:

- The LOS framework and corresponding output tables provide data that is user friendly and easily assimilated by elected officials, stakeholders and the public alike,

- The LOS output provides a snapshot for all 8,760 hours in a year and comparative longitudinal analysis of pre and post improvement scenarios for a 20+ year period that reflects multi-dimensional/multi-variant characteristics,
    - LOS Policy
    - Direction of travel
    - Segregation by vehicle type
    - PIL infrastructure or staffing levels
    - Various processing time scenarios
- The LOS framework and output is complementary to 30th highest hour design practice and can assist in corroborating simulation model results,
- The value of the LOS output versus simulation models is that typically simulation models are only run for the design year based on a 30th highest hour volume to evaluate a facility design whereas, one run of the LOS model provides output for every hour in every year of the planning period and summarizes the results in an easy to interpret spread sheet. The LOS model can be modified to reflect different scenarios by simply recalibrating the parameters. It would be uneconomical and impractical to run a simulation model for anything other than a 30th highest hour design.

Findings from the Pembina-Emerson study have demonstrated that the LOS framework and corresponding output tables are a powerful and descriptive policy-level tool that can be used by decision-makers to better evaluate, assess and understand the implications (required investments, phasing considerations, benefits) of various POE improvement scenarios.

Acknowledgments

Transport Canada: Funding partner for the Pembina-Emerson study

Gannett Fleming: Conducted simulation modelling for the Pembina-Emerson POE, assisted with LOS framework calibration and prepared the final study report

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