Data Management and Emissions Estimation for a Ports Landside Emission Inventory for the Vancouver Fraser Port Authority

Bryan McEwen and Gary Olszewski
SENES Consultants Limited, 1338 West Broadway, Suite 303, Vancouver, B.C., V6H 1H2, Canada.
bmcewen@senes.ca, golszewski@senes.ca

ABSTRACT

A Landside Emissions Inventory for over 90 marine terminals under the administration of the Vancouver Fraser Port Authority in British Columbia was completed in 2008. The Inventory is activity based, with estimates of common air contaminants, air toxics and fuel consumption at several different levels of resolution. Data collection was challenged by the wide spatial distribution of terminals in the region and the level of effort terminal managers were willing to expend.

To minimize a prohibitive amount of 'leg work' in capturing accurate data for cargo handling, trucking and rail activity, an excel questionnaire was developed and linked to an emissions inventory (EI) database. The EI database was configured with a matrix of EPA MOBILE and locomotive emission factors to link with trucking and rail activity input fields in the questionnaire. More significantly, the EPA NONROAD methodology and data tables were linked such that the NONROAD emissions model was mimicked internally, bypassing model defaults. The result was a largely automated, functional database EI model with routines to import a terminal's activity information, complete all emissions calculations and conduct accuracy checks based on fuel criteria. In addition, the estimation routines were complemented so that use of alternative fuels (e.g., biodiesel) could be handled.

The EI model minimized manual calculation efforts and allowed more time to be spent on dialogue with terminal operators to improve activity level estimates. The database was linked with the input terminal questionnaires, facilitating scenario testing and forecasting, which was a required component of the EI project.

INTRODUCTION

The Port of Vancouver is the largest port in Canada and the most diversified port in North America. It is a deep-water port with 276 km of coastline. Its harbour area includes the Burrard Inlet, Indian Arm, Port Moody, English Bay and all other tidal waters lying east of a line between Point Atkinson light to the west point of Point Grey, excluding False Creek. Also included is a narrow coastal strip in the Strait of Georgia encompassing the approach to the Fraser River, Sturgeon Bank, Roberts Bank and Boundary Bay. The Vancouver Port Authority (VPA) managed the activities of over 50 marine terminals in 2005. On January 2008, the VPA amalgamated with the two Fraser River port authorities to create the Vancouver Fraser Port Authority which now has over 90 tenants. The

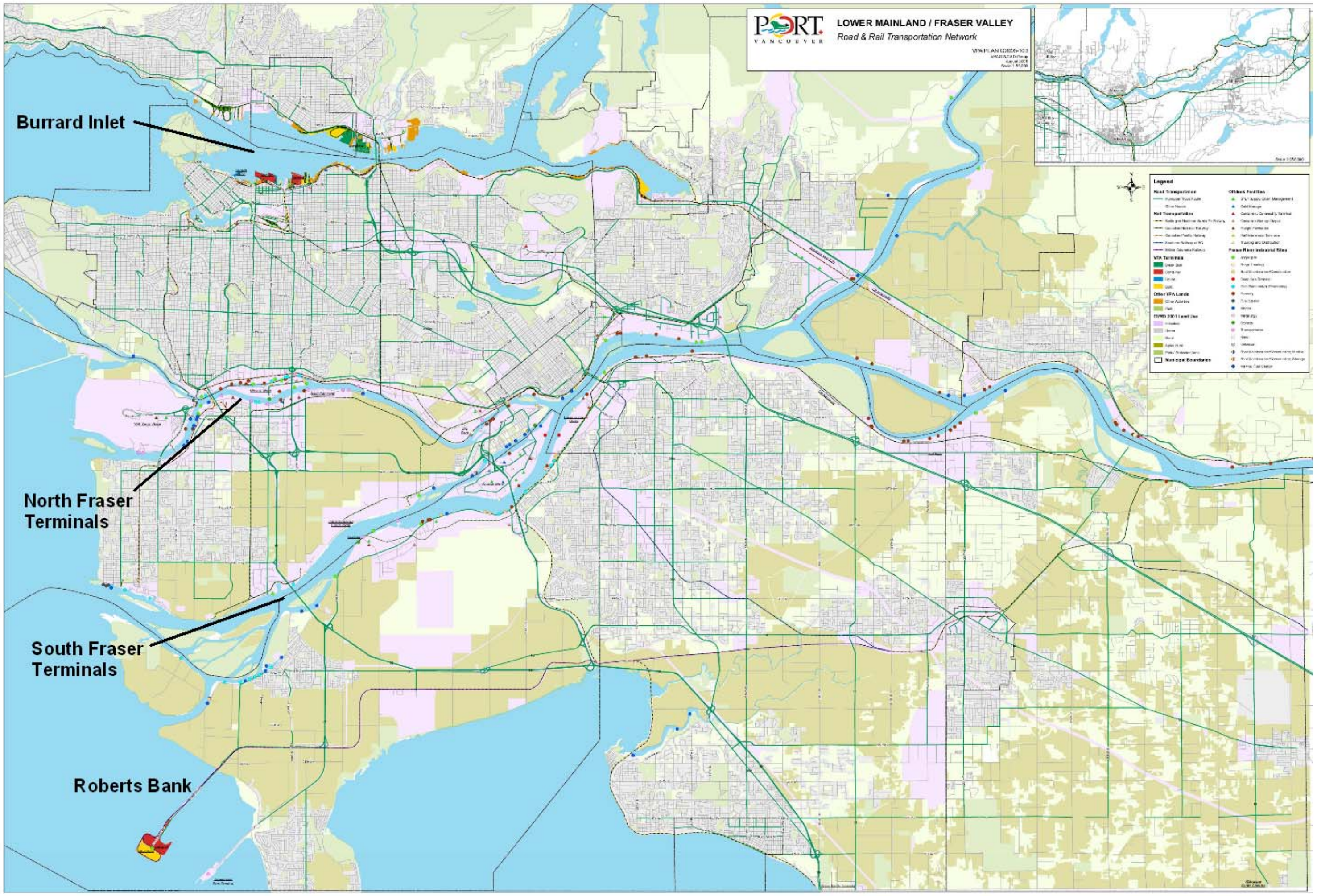
VFPA, in association with Metro Vancouver and Environment Canada, set the terms of reference for the completion of a Port Landside Emission Inventory ('VFPA Inventory') for the activity year 2005, with additional inventories in 5 year increments from 1990 to 2030. Figure 1 shows the Lower Fraser Valley portion of British Columbia, with the locations of the VFPA marine terminals.

The VFPA Inventory itself was to follow current best-practices, which effectively meant use of an Activity Based Inventory (ABI) approach, where all emission estimates (to the degree possible) directly relate to engine or vehicle activity levels (kms of travel or hours of use). It was immediately recognized that the collection of activity data for the individual terminals would represent the greatest challenge to completing the VFPA Inventory to a high degree of quality (and in a reasonable amount of time). In addition to the 'typical' emissions inventory (EI) development practices, the following criteria were made part of the terms:

- Account for emissions in many different activity 'modes' (for example, truck idling time at facility gates);
- Account for any emission reduction initiatives that have occurred at the marine terminals prior to 2005;
- Account for any emission reduction initiatives that have occurred since 2005;
- Account for any emission reduction initiatives that are planned for the future.

Since the collection and management of activity data would clearly be integral to the VFPA Inventory, a spreadsheet questionnaire was developed that could be used by each of the terminals to input operational activity. In addition, a database was constructed that could import the questionnaires, identify conflicting information and create emission summaries effectively. A significant amount of effort was spent in creating a user-friendly spreadsheet form and a database system that could indicate appropriate actions to take as the terminal data were being collected.

Figure 1. Lower Fraser Valley and VFPA Terminals (photo courtesy of VFPA).



METHODS

The specific methodologies to create the VFPA Inventory were established by the authors. However, previous port landside inventories completed for U.S. ports (and specific Canadian terminals) have practically defined a methodology that is appropriate to follow. This methodology can be expressed as follows:

- Collect annual vehicle and engine activity levels for each marine terminal;
- Collect fleet characteristics to support terminal activities (e.g., highway trucks);
- Determine activity based emission factors to complement the activity data collected;
- Directly relate all emission estimates to operational activity (kms of travel, hours of use, etc);
- Use on-road (trucking) activity-based emission rates from the U.S. EPA MOBILE[1] emissions model;
- Use rail locomotive activity based emission rates from current research programs[2,3]; and,
- Use off-road/non-road activity based emission rates from the U.S. EPA NONROAD[4] emissions model;
- Estimate air toxic emissions by use of the EPA SPECIATE model.

A dyamic approach to EI generation was followed, with use of a database model that linked the capabilities of the EPA emissions models to the degree possible.

Inventory Questionnaire

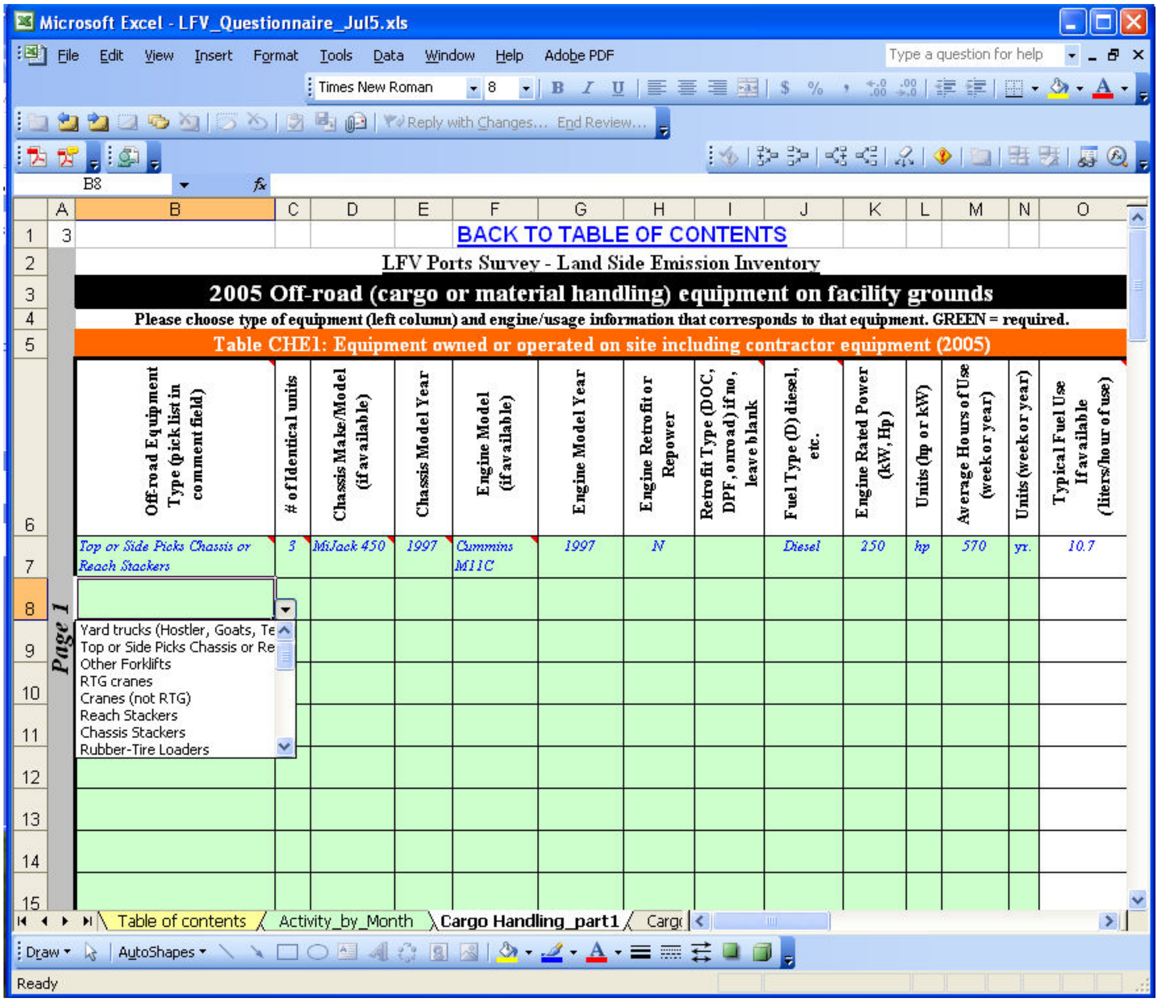
A multi-worksheet spreadsheet form was created to collect terminal activity in a consistent manner. To the degree possible, the questionnaire fields were constructed so that a terminal operator would choose from available options rather than enter possibly unique responses. Six separate worksheets make up the questionnaire form: Introduction sheet with links to following pages, Activity by Month sheet to distinguish emissions by season, Cargo Handling Equipment (I) sheet to collect specific dockside equipment types and usage, Cargo Handling Equipment (II) sheet to collect total fuel(s) consumption and reduction initiatives, Trucking sheet to collect highway truck and facility truck equipment and usage (and reduction initiatives) and Rail sheet to collect transport and local locomotive activity rates.

Figure 2 shows the Inventory questionnaire with the 'Cargo Handling' worksheet open. The worksheet fields relate to the input data necessary to complete NONROAD emission estimates. A terminal operator would use drop down lists to select the following parameters:

- Equipment Type (matching NONROAD port equipment descriptors);
- Number of equipment pieces (of identical design);
- Engine model year;
- Whether or not an engine retrofit or re-power was completed;
- Fuel type;
- Engine rated power; and,

- Average hours of use (per week or per year).

Figure 2. Inventory Questionnaire - Cargo Handling Equipment (I)



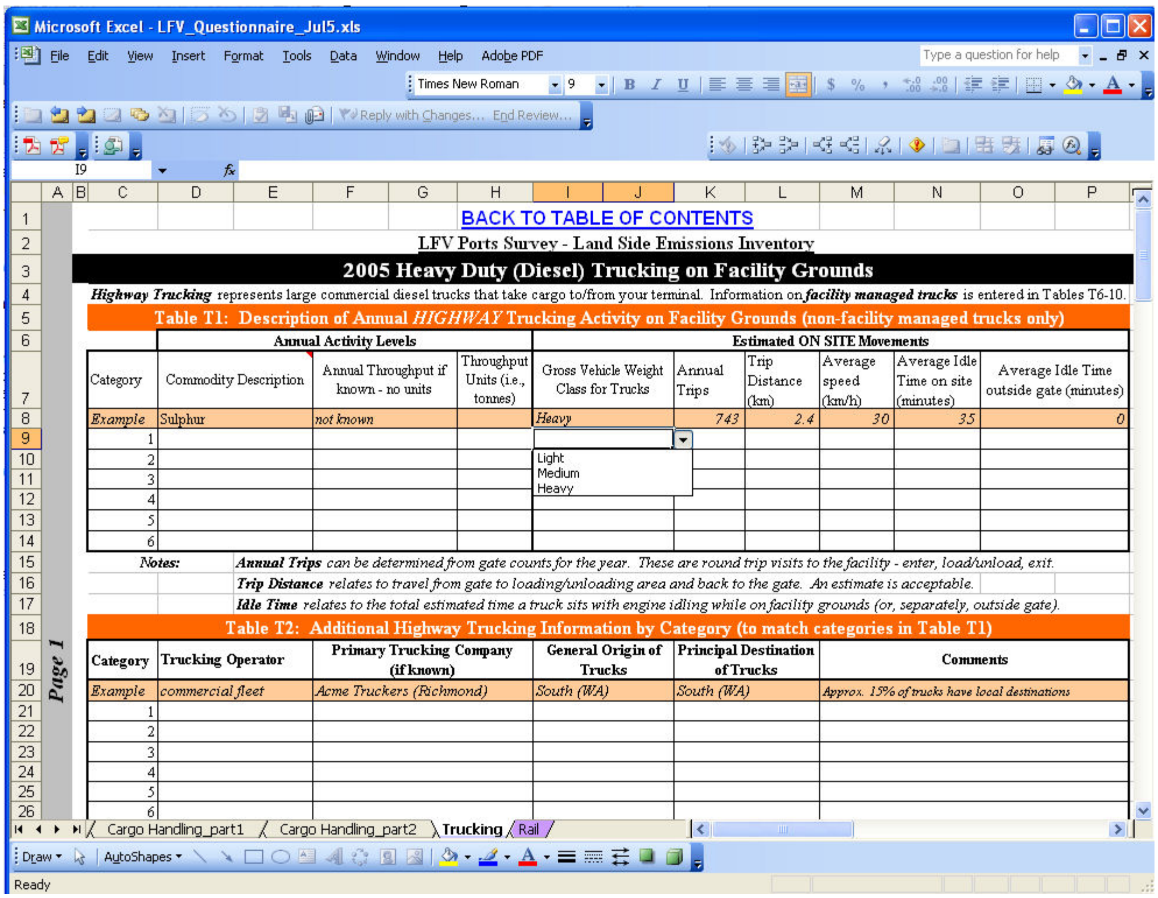
Several additional fields were included that were not necessary to complete the NONROAD calculations. One additional field was added with the intent of bypassing NONROAD engine load assumptions. This field is 'typical fuel use per hour'. Unfortunately, very few responses were achieved for this field and therefore the NONROAD engine load assumptions were not bypassed. Total fuel consumption for cargo handling equipment was collected from each terminal to essentially 'close the loop' on emission estimates such that the NONROAD estimates would not imply greater fuel use than actual. However, the 'typical fuel consumption per hour' field would have allowed the emission estimation methodology to better account for distribution of emissions by equipment type (e.g., what percentage of total emissions relate to forklifts) and deterioration of emission rates with age (as engines wear, emission rates for some air contaminants increase). This issue is not large in significance and reflects operational realities, since in most cases specific fuel consumption data simply do not exist at the terminal level.

Fewer data fields and entry lines were necessary for the Trucking sheet. The following fields were necessary to complete emission estimates with MOBILE emission rates:

- Highway truck vehicle weight class;
- Highway truck annual trips (e.g., gate count);
- Highway truck trip travel distance and average speed on site;
- Highway truck average idling times at gate and on-site;
- Facility truck type and age profile (from several defined profiles); and,
- Fuel type(s) and annual consumption level(s).

Additional information fields were collected so that a potential future need to estimate trucking emissions beyond facility boundaries could be addressed. Figure 3 shows the first two tables of the Inventory questionnaire ‘Trucking’ sheet.

Figure 3. Inventory Questionnaire - Trucking Sheet.



BACK TO TABLE OF CONTENTS

LFV Ports Survey - Land Side Emissions Inventory

2005 Heavy Duty (Diesel) Trucking on Facility Grounds

Highway Trucking represents large commercial diesel trucks that take cargo to/from your terminal. Information on ***facility managed trucks*** is entered in Tables T6-10.

Table T1: Description of Annual *HIGHWAY* Trucking Activity on Facility Grounds (non-facility managed trucks only)

	Annual Activity Levels			Estimated ON SITE Movements					
Category	Commodity Description	Annual Throughput if known - no units	Throughput Units (i.e., tonnes)	Gross Vehicle Weight Class for Trucks	Annual Trips	Trip Distance (km)	Average speed (km/h)	Average Idle Time on site (minutes)	Average Idle Time outside gate (minutes)
Example	Sulphur	*not known*		*Heavy*	*743*	*2.4*	*30*	*35*	*0*
1									
2									
3									
4									
5									
6									

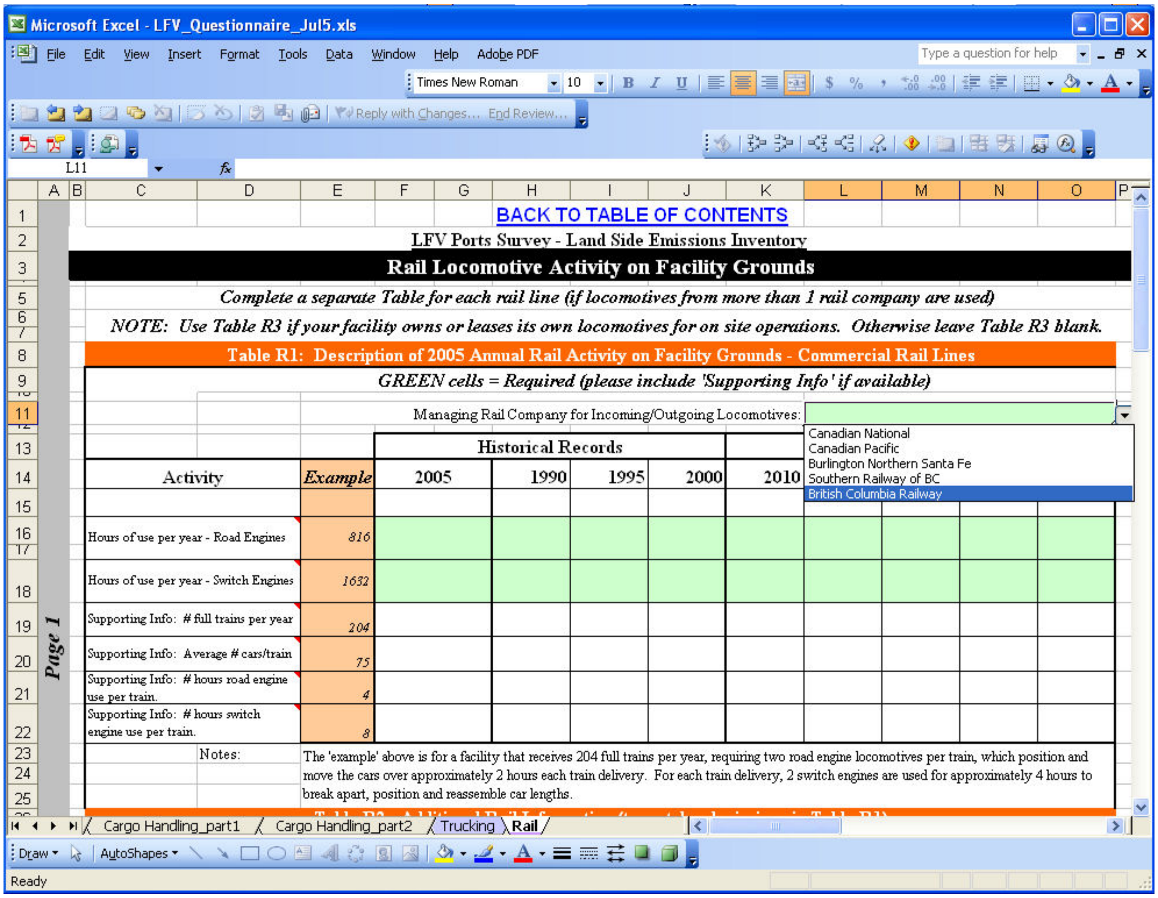
Notes: ***Annual Trips*** *can be determined from gate counts for the year. These are round trip visits to the facility - enter, load/unload, exit.*
Trip Distance *relates to travel from gate to loading/unloading area and back to the gate. An estimate is acceptable.*
Idle Time *relates to the total estimated time a truck sits with engine idling while on facility grounds (or, separately, outside gate).*

Table T2: Additional Highway Trucking Information by Category (to match categories in Table T1)

Category	Trucking Operator	Primary Trucking Company (if known)	General Origin of Trucks	Principal Destination of Trucks	Comments
Example	*commercial fleet*	*Acme Truckers (Richmond)*	*South (WA)*	*South (WA)*	*Approx. 15% of trucks have local destinations*
1					
2					
3					
4					
5					
6					

The Rail sheet of the Inventory questionnaire was relatively simple, reflective of the fact that terminal operators do not manage locomotive activities in any detail (although there were a few exceptions). Although scheduling is managed, terminal operators have little knowledge of locomotive type (e.g., switch or road engine) and age but can identify appropriate rail companies and hours of activity on-site. Figure 4 shows the first table of the Inventory questionnaire 'Rail' worksheet.

Figure 4. Inventory Questionnaire - Rail Sheet



Inventory Database

MS Access software was used to construct a database system to import the terminal activity questionnaires and achieve detailed emission estimates following the general methodology identified. This was primarily achieved by constructing a number of emission factor tables that the database routines would call upon to link with information present in a terminal questionnaire form.

A number of MOBILE model simulations were completed to prepare an emission factor (g/km) table representative of all truck types, ages and operational patterns (speeds) serving the VFPA terminals. In addition, a literature review was conducted to prepare a table of appropriate truck engine idle emission factors (g/hour). A practical limitation for utilizing the specific emission factors exists, due to the fact that terminal managers do not know the age distribution of the highway trucks that arrive and depart from a particular facility. This limitation was addressed by constructing an age and size distribution for container trucks (deriving from VFPA licensing records) and owner-operator trucks (based on visual surveys completed by the authors and additional licensing data). These distributions were used to establish MOBILE sets of emission factors appropriate to type of marine terminal and activity year. In all cases, the existing age distribution by relative year was assumed to be representative for all Inventory backcast and forecast years. In other words, if 15% of current trucks are 2 years old or newer, this criterion was applied for all other inventory years as well. In general, this application of MOBILE is consistent with its framework; the model is designed to represent fleet-average emission rates and not emission rates for individual vehicles.

A similar procedure was followed to determine tables of locomotive emission factors that could be linked to the questionnaire forms. In this case, the emission factors determined were representative of all terminals and linkage was based on rail company and type of locomotive (switch or road engine) identified. Emission factors were available by throttle notch for a number of switch and road (line haul) engines and these were linked to typical engine models and ages used by each rail company. The engine criteria were determined from anecdotal information from the rail companies and an annual publication produced by the Railway Association of Canada[5].

Due to limited activity information, global assumptions had to be applied to develop appropriate emission rates. The following assumptions were used to develop ‘line haul’ and ‘switch’ emission rates:

- Line haul ‘work’ activity in the Fraser Valley occurs with use of Throttle Notch settings 3 and 4 (equal weighting);
- Switch ‘work’ activity in the Fraser Valley occurs with equal use of Throttle Notch settings 1, 2, 3 and 4.

To account for different idling activities for the different terminal types, emission rates in g/hour were generated for work and idle separately. This differs from the usual rail EI approach which relies on assumed duty cycles inclusive of idling periods (which tend to be quite high). It was found that locomotive activity at some terminal types involves substantial idling time whereas other types had little idling activity on average. The separation of idle and work emission rates allowed for terminal-specific effective duty cycles to be used in the emissions estimation. In addition, this approach facilitated the assessment of idle reduction initiatives that were expected in future years.

NONROAD Linkage

The NONROAD model reports an in-use emission factor as an aggregate value representative of the (U.S.) fleet age distribution. For this reason, an emission factor extracted from NONROAD could not be directly applied to the piece-by-piece activity data collected for the marine terminals in the Lower Fraser Valley. A single piece of cargo handling equipment in question may not be well represented by the aggregated emission factor if it is much newer or older than the average age within the NONROAD fleet. This issue is important for the VFPA Inventory, since the effect of replacing older equipment was to be accounted for on a terminal by terminal basis. Further, any reduction strategy involving technology modifications (hybridization, catalysts, particulate traps, etc) and different fuels (biodiesel mixes, on-road diesel, ultra-low sulphur diesel, etc) had to be assessed in a consistent and transparent manner.

The mis-match between the appropriate estimation tool (NONROAD) and the expressed goals of the VFPA Inventory was addressed by mimicking the NONROAD estimation methodology (specifically, generation of emission factors) without the aggregation step included. Within the NONROAD model there are two core functions:

1) Activity Definition – population, age distribution, fleet turnover, equipment size categories, average horsepower, yearly hours of use, and growth changes.
2) Emission Factors – base emissions by technology class, in-use deterioration rates, load factors, average engine life, and fuel characteristics.

The VFPA Inventory calculations require only the *Emission Factors* functionality without the influence of the activity profiles. Determining emission factors consistent with the implications of the emissions data included within the NONROAD model is possible because the NONROAD methodology is well documented and discussed through generally available literature provide by the EPA[6,7].

The base emission factors information in the functional NONROAD model is provided in an easily accessible text format which was simply copied over from NONROAD to the VFPA Inventory database model. The basic equation for determining an in-use emission factor is shown in Equation 1 (for particulate matter (PM) a sulphur-PM adjustment is additionally used);

$$EF_{\text{in-use}} = EF_{\text{zero-hour\_base}} \times DF \qquad (1)$$

where: DF = deterioration factor

Determining the ***zero-hour base emission factor*** and the ***deterioration factor*** is well explained within the available NONROAD guidance documents and is not discussed in detail here. The in-use emission factor represents a snapshot emission rate for a single year and piece of equipment, given its age and yearly usage rate. Application of Equation 1 was dynamically facilitated in the VFPA Inventory database so that appropriate emission rates for each individual piece of cargo handling equipment were established once the terminal questionnaire information was ingested.

Due to the fact that NONROAD application is an accepted method of determining cargo handling equipment emissions in Canada, a reasonable quality control procedure would be to compare the VFPA Inventory emission factor estimates against NONROAD emission factor estimates, given an equivalent input basis. The NONROAD model itself applies a defined scrappage curve and a set of population adjustment factors to establish an age distribution (age and population percentage) for each type of equipment represented. The NONROAD model then applies the age distribution against the available age/tech year emission factors to generate an aggregated emission factor for use in EI reporting requirements.

In order to compare the emission factors determined in the VFPA Inventory model to those generated from the NONROAD model, the effects of age distribution on the emission factor aggregation had to be nullified in NONROAD. To achieve this, adjustments were made to the values of *yearly hours of activity*, *load factor*, and *hours of life* in NONROAD. The NONROAD *yearly activity hours* were set at 2000 hours, the *load factor* set to 1.00 and the *hours of life* set to 1000 hours. With these values, the NONROAD model will effectively evaluate only a single model year for a piece of equipment based on the default scrappage curve (which defines 100% scrappage at twice the life expectancy). This approach enacts full emission factor deterioration as well. The same adjustments were made to the VFPA Inventory data tables (i.e., they were again copied over from the now modified NONROAD model).

The resulting emission factors from this test are not meant to represent real world values but allow for model comparison on an equivalent basis (which could not otherwise occur). Table 1 lists the seven pieces of equipment used for comparison, representing a range of fuels and equipment types.

Table 1 - Equipment List for Testing

Fuel	Equipment	SCC	Power(hp)	Model year
Diesel	Gas Compressors	2270006020	90	2005
	Cranes	2270002045	412	2005
	Yard Truck (Terminal Tractor)	2270003070	221	2005
CNG	Gas Compressor	2268006020	69	2005
LPG	Cranes	2267002045	69	2005
4 stroke Gasoline	Cranes	2265002045	37	2005
2 stroke Gasoline	Crusher/grinder	2260002054	2	2005

The two models were run for the inventory year of 2005 with the equipment model year also of 2005. The results from the model runs are provided in

Table 2, listing both the VFPA Inventory emission factors and the NONROAD factors. The VFPA Inventory expresses the factors by technology type (if a new type is introduced within the year) and effective value for the year. NONROAD simply states one emission factor (which is an effective value for the year). For the model year of 2005, the diesel equipment and the 2-stroke gasoline equipment indicate transitional years for technology types and thus different base emission rates. Following the NONROAD methodology, the 'Tech Ratio' is used to appropriately weigh the two base rates to achieve an effective rate for the year. The results presented in

Table 2 clearly illustrate that the internal calculations used within the VFPA Inventory database model duplicate the NONROAD calculations for determining emission factors for individual pieces of equipment.

Table 2 - Emission Factor Comparison for the VFPA model and NONROAD

SCC	Tech Type	Tech Ratio	Emission Factors (g / hp-hr)						
			HC_{exh}	NO_x	CO	PM_{10}	SO_2	CO_2	HC_{cnk}
2270006020	T1	0.2	0.5387	5.7344	2.6094	0.6565	0.7467	588.6510	0.0108
	T2	0.8	0.3826	4.7423	2.6094	0.3556	0.7474	589.1490	0.0077
	VFPA_Effective		**0.4138**	**4.9407**	**2.6094**	**0.4157**	**0.7473**	**589.0494**	**0.0083**
	NONROAD		**0.4138**	**4.9407**	**2.6094**	**0.4157**	**0.7473**	**589.0493**	**0.0083**
2270002045	T1	0.2	0.2072	6.1645	1.4423	0.2624	0.6728	530.3822	0.0041
	T2	0.8	0.1758	4.3791	0.9248	0.1933	0.6730	530.4824	0.0035
	VFPA_Effective		**0.1789**	**4.5576**	**0.9766**	**0.2002**	**0.6730**	**530.4724**	**0.0036**
	NONRAOD		**0.1789**	**4.5576**	**0.9766**	**0.2002**	**0.6730**	**530.4723**	**0.0035**
2270003070	T1	0.2	0.3315	5.4067	1.2551	0.4241	0.6797	535.7735	0.0066
	T2	0.8	0.3309	3.8241	1.2551	0.2375	0.6797	535.7756	0.0066
	VFPA_Effective		**0.3309**	**3.9824**	**1.2551**	**0.2562**	**0.6797**	**535.7754**	**0.0066**
	NONROAD		**0.3309**	**3.9824**	**1.2551**	**0.2562**	**0.6797**	**535.7753**	**0.0066**
2268006020	NGT251	**VFPA**	**17.5496**	**3.6225**	**48.2936**	**0.0630**	**0.0010**	**438.0228**	**0.0000**
	NONROAD		**17.5496**	**3.6225**	**48.2936**	**0.0630**	**0.0010**	**438.0228**	**0.0000**
2267002045	LGT251	**VFPA**	**1.1890**	**3.6225**	**48.2936**	**0.0630**	**0.0011**	**548.1249**	**0.0000**
	NONROAD		**1.1890**	**3.6225**	**48.2936**	**0.0630**	**0.0011**	**548.1248**	**0.0000**
2265002045	G4GT251	**VFPA**	**1.6449**	**2.4311**	**69.0336**	**0.0756**	**0.0127**	**695.0930**	**0.0000**
	NONROAD		**1.6449**	**2.4311**	**69.0336**	**0.0756**	**0.0127**	**695.0929**	**0.0000**
2260002054	G2H4C2	0.8	47.5599	1.4910	175.7080	9.9330	0.0188	1037.7048	0.0000
	G4H42	0.2	54.2430	1.1260	821.7500	0.1260	0.0191	1052.5603	0.0000
	VFPA_Effective		**48.8965**	**1.4180**	**304.9164**	**7.9716**	**0.0189**	**1040.6759**	**0.0000**
	NONROAD		**48.8965**	**1.4180**	**304.9163**	**7.9716**	**0.0189**	**1040.6758**	**0.0000**

CONCLUSION

The VFPA Inventory project is on-going and due to be finished in June or July of 2008. Interim presentations of the VFPA Inventory database model to the port authority have been well-received, due in part to the built-in flexibility of the model to address additional queries and research questions of interest to the port members. The dynamic linkage of a terminal questionnaire with the emission estimation routines within the model will allow the port authority to offer help to terminal managers seeking to estimate the benefits of replacing aging equipment with alternatives. The database model is simplified to the degree that additional support from the contractor will be minimized.

A key difference between the VFPA Inventory and other port landside inventories that have been developed recently is that scenario or 'what-if' questions can readily be addressed. This makes the VFPA Inventory appropriately labeled as a dynamic EI model as opposed to a static model that is used for a single snapshot evaluation. In addition to this, the significant effort in capturing the terminal-level activity data is honoured; a future update to the landside EI can be accomplished with a minimum level of effort for the port and its tenants. Adjustments can be made to the activity questionnaires where appropriate and the database model can be upgraded by 1) re-generating the MOBILE and rail emission rates, and 2) by replacing the NONROAD emissions data tables (if the model is updated).

The MOBILE model is well-suited to achieve emission estimates on a specific vehicle fleet basis (exception idle emission rates). Although NONROAD has built-in aggregation to account for population and age distributions, the model has sufficient documentation to allow modification to suit inventory development at an engine by engine resolution. The activity-based approach was followed successfully for the VFPA Inventory without an onerous level of effort, yielding a dynamic EI database model that benefits from the substantial development history of the EPA emissions models.

The dynamic EI approach used offers the following benefits:

- The database helps ensure data accuracy and consistency through defined relationships and automatic reality checks;
- The database facilitates a formalized quality analysis procedure that clients are more commonly demanding; in addition to automatic consistency checks, automatic facility reports are generated at the emission/fuel summary level to send to terminal managers for comment;
- A change in emissions methodology is immediately carried through all aspects of the Inventory;
- Much control is possible for data export (e.g., GIS) and data presentation;
- Both activity data and emissions methodology are fully preserved so that updates can be achieved with a reasonable amount of effort.

REFERENCES

1. U.S. Environmental Protection Agency. “User’s Guide to Mobile 6.1 and Mobile 6.2. Mobile Source Emission Factor Model”. EPA document 420-R-03-010, 2003.

2. Fritz, S.G. “Diesel Fuel Effects on Locomotive Exhaust Emissions. Final Report”; Prepared for the California Air Resources Board, Sacramento, CA 2000.

3. U.S. Environmental Protection Agency. “Locomotive Emission Standards. Regulatory Support Document”. Office of Mobile Sources, 1998.

4. U.S. Environmental Protection Agency. “User’s Guide for the Final NONROAD2005 Modell”. EPA document 420-R-05-013, 2005.

5. Environment Canada. “Locomotive Emissions Monitoring Program 2005”. Transportation Division, Clean Air Directorate, Environment Canada. Document EPS 2/TS/20, 2006.

6. U.S. Environmental Protection Agency. “Exhaust and Crankcase Emission Factors for Nonroad Engine Modeling – Compression Ignition”; Prepared for the U.S. Environmental Protection Agency, Ann Arbor, MI, April 2004. EPA Document EPA420-P-04-009, NR-009c.

7. U.S. Environmental Protection Agency. “Exhaust Emission Factors for Nonroad Engine Modeling – Spark Ignition,”; Prepared for the U.S. Environmental Protection Agency, Ann Arbor, MI, April 2004. EPA Document EPA420-R-05-019, NR-010e.

KEYWORDS

Emission Inventory
MOBILE
NONROAD
Port
Landside
Cargo Handling
Database
Locomotive