Developing an Integrated Model to Quantify Port Emissions

Tracy Fidell, P.E.
Port Engineer
Moffatt & Nichol
160 Franklin St, Suite 300
Oakland, CA 94607
(510) 645-1238 (phone)
(510) 645-1010 (fax)
tfidell@moffattnichol.com
1. Introduction

Although air pollution is an important issue for many industries, air emissions from marine container terminals have recently attracted unprecedented concern in Southern California and elsewhere. The former mayor of Los Angeles mandated no net increase in air emissions from the city’s port beyond year 2001 levels. This is a daunting goal in light of forecasts for compounded cargo growth of 4 to 6% until the year 2030. Ports and government agencies alike clearly have a pressing need for a tool to quantify the amounts of emissions produced by marine terminals.

This paper documents the development of an integrated computational model that quantifies air emissions produced from day to day port operations. The user can change the operating parameters and easily identify the effect of those changes on port-wide emissions. The model allows users to determine the major sources of air pollution at the port, and target the most effective methods for reducing emissions.

This paper describes the goals in creating the model and explains the approach in developing it. One of the bigger challenges encountered was to make the model flexible enough to be used at any port, not just in Los Angeles or Long Beach (the two ports in San Pedro Bay), while at the same time keeping it simple enough to be useful.

2. Background

2.1 History and Importance

Port and shipping related activities have always produced air emissions. However, it is only recently that port-related emissions have attracted widespread attention. The opening of Port of Los Angeles’ Pier 400 (590 acres of rock dike-retained hydraulic landfill, the largest single operator container terminal in the world) three years ago did not merit a story with the L.A. Times. These days, stories about how the two San Pedro Bay ports are addressing air quality issues are in the news nearly daily.

The primary reason for the enhanced local interest in port emissions is the city’s requirement of no net increase in emissions from the year 2001, despite predictions that San Pedro Bay port traffic will more than triple by 2020.

California, out of necessity, has a long history of national leadership when it comes to air quality control. In many instances, the South Coast Air Quality Management District has been the first to tackle difficult issues of air quality management. Solutions like creating air quality control bodies and regulating the types of fuel burned or the amounts of emissions generated often start in Southern California and spread from there to the rest of the state and nation. Current trends in air quality management in Southern California are a good indicator of future trends in national air quality management, making port air emissions a very relevant issue.
2.2 Traditional Methods for Estimating Port Air Emissions

The current accepted practice for estimating port air emissions is to establish a “baseline” inventory and to extrapolate future emissions from it. These inventories are created by listing the existing equipment and relying on field surveys and maintenance records to understand the hours of operation for each piece of equipment.

One weakness of this approach is that the inventory is only as good as are the data collected. The data collection process itself is labor intensive since records are often not kept electronically. Records in different formats must be carefully examined and manually entered into a database. By the time a baseline inventory is created, it is usually outdated.

Another problem with this approach is that it has questionable benefit in predicting future emissions. As time passes and throughput grows, equipment and operating characteristics of the terminal change in many ways. A direct relationship between emissions and throughput does not exist because emissions depend heavily on operating strategy. It is a vast oversimplification to predict future emissions by increasing baseline emissions proportionally to the expected increase in throughput.

2.3 This Model’s Approach to Estimating Port Air Emissions

The model Moffatt & Nichol is developing calculates total emissions from all container terminal activities: the vessels, tugs, locomotives, container handling equipment, on-terminal trucks (hostlers) and road trucks. The model can be calibrated using established emissions inventories and throughputs to create a baseline. The baseline can then be compared with anticipated growth scenarios to determine the net effect on emissions.

The main advantage of using a model is that it enables the user to predict future air emissions both by increasing throughput and by adjusting operating characteristics. The model is especially useful for comparing air emissions resulting from different operating strategies. It offers a convenient way to compare and prioritize air emission reduction strategies that can be further analyzed for cost-effectiveness.

The emissions model parallels the port planner’s customary approach to analyzing port operations. Previously developed spreadsheet models for the berth, rail yard, gate, and storage yard operations have been linked together and extended to consider emissions as well. The goal is to create a tool for port planners that is entirely transparent and accessible, in the sense that all of the inputs and assumptions can be viewed and changed at will.
3. Approach
Figure 3.1 shows the four operating systems that make up a container terminal. The types of equipment involved in each operation are listed in blue alongside the operation. This model estimates the emissions produced by all the equipment shown below.

Figure 3.1
Terminal Activities and Related Emissions Producing Equipment
Figure 3.2 shows a flow chart of how the different pieces of the model work together. A discussion of the methodology used in each step is presented in this section and the next.

3.1 The Equation

Air emissions calculations essentially boil down to the following basic formula:

\[
\text{Grams of pollutant} = (\text{Total Installed Power}) \times (\text{Emission Factor}) \times (\text{Load Factor for Mode}) \times (\text{Time in Mode})
\]

Most of the terminal model is dedicated to determining the final component of the equation: time in mode. This is the main focus of this paper and will be described in the next section. The approaches to the first three components are given briefly below.
3.2 Total Installed Power
A separate spreadsheet is used to determine the installed power for a “representative” number of machines from each fleet of equipment. A fleet of equipment is rarely made up of identical machines. There can be considerable variations in weight, engine size, and age that complicate finding a representative piece of equipment. This spreadsheet can be used to simulate the reality of how individual machines within a fleet are deployed. It can assign the most work to the newest, nicest pieces of equipment and use the older pieces of equipment to do the remainder of the work. A weighted average of the individual machines is used to determine the installed power for the fleet.

3.3 Emission Factors
Emission factors are used to convert power consumption into grams of pollutant by type: NOx, SOx, PM2.5, PM10, HC, and CO. Emission factors for the relevant pollutants are drawn from the most recent studies on ship, tug, rail, truck, and container handling equipment. By having emission factors be a selectable input in the emission calculation spreadsheet, a user can easily test the effect of improvements in fleet emission rates on port emissions both on and off the terminal.

The terminal model is needed if a user wanted to explore the potential benefits of making changes to the operations like increasing on-dock rail, using a buffer in the rail yard, changing the type of equipment used, extending gate hours, or becoming more automated. These types of operational adjustments change more than the emission factors; they change the time in mode for the equipment.

3.4 Load Factor for Mode
To begin this discussion the term “mode” must be defined. For this model’s purposes, a mode is a set of activities with similar power requirements. Each piece of equipment does a variety of tasks to accomplish the work done at a terminal. A task can be to deliver a container to a road truck from a stack, or to transport a container from the rail yard to the storage yard. Each task, or cycle, is composed of a series of sequential activities and these activities are grouped into modes; this will be discussed in greater depth in the next section.

For example, the five modes defined for an RTG are: gantry, trolley, lift loaded, lift unloaded, and “idle.” The idle mode includes all time spent positioning the spreader, attaching or detaching from the container, lowering the spreader (with or without a load), and all wait times. The three modes for a hostler are: drive loaded, drive unloaded, and idle.

The model uses average equipment and container weights to calculate the amount of power required in each mode. The load factors are found by dividing the required horsepower by the total installed horsepower for each type of equipment. The load factors are compared with standard U.S. Environmental Protection Agency (EPA) and California Air Resources Board (CARB) defaults as a check. They can also be compared with real duty cycle data where those are available.
The assumed load factor for idling is 10% of installed horsepower for every type of equipment.

4. Time In Mode

The bulk of the model is dedicated to finding the time spent in each mode for each type of equipment. This is done by describing each type of cycle for each type of equipment and then determining the number of cycles required to complete the work prescribed by the vessel call schedule.

Three modules are used to find the number of cycles done in a year – stevedoring, gate, and rail. These will be described in this section. A fourth module is used to calculate miscellaneous moves, like grooming the stacks or re-handles that are not accounted for elsewhere.

4.1 Cycle Descriptions

The cycle description is a step-by-step representation of the work done by a single piece of equipment to accomplish a task. The cycle begins and ends in the same place. One example of a task is for a hostler to transport an import from a ship crane to the container stacks in the storage yard and then return to the ship. Another example of a task would be for the stacking equipment to take the container off the yard tractor, place it in the stack, and then return to the start position and wait for the next task.

Each cycle is composed of a set of sequential activities. Continuing the examples above, the cycle for a hostler serving a dock crane discharging a ship might start by driving with a load from the crane to the yard, waiting for service in the yard, driving back with no load, and waiting under the crane for the next task. The cycle for an RTG receiving imports might be: gantry to position, trolley unloaded, lower unloaded, position spreader and attach to box on hostler, lift loaded, trolley loaded, lower loaded, position box and set it on stack, lift unloaded, and then wait for the next task.

The cycle duration is calculated from a known or assumed productivity. The time required for each activity is calculated from known or assumed distances and drive speeds. If there is any time left over in the cycle, it is attributed to time spent waiting for next task.

The model allows the user to enter a percent of moves performed while “double-cycling.” Double-cycling means that productive moves are done on both legs of the cycle. For instance, a hostler can take an import from the dock crane to the stacks and then return with an export container. Double-cycling can also happen when draying containers to and from the rail yard.

4.2 Stevedoring Operations

The model reports the number of annual calls for each size of vessel. It also reports the amount of time each vessel stays on berth per call.
Pilot information, where available, is used to determine the load factors used by the vessels at each stage of their arrival: cruising on the approach, slow cruising to the harbor entrance, and then maneuvering within the harbor and during mooring. The user enters the distances traveled by the vessel from the Air Quality District Boundary to the berth, and the expected speeds of travel on each leg.

A number of tug boats are assigned depending on vessel size. Tugs are assumed to have a “home base.” The user enters the distance from home base to the harbor entrance where the tug meets a vessel, and the distance from the berth back home.

Dock cranes are typically powered by electric motors and shore current. But since some ports do use diesel powered dock cranes, the model reports these power demands as well. The model automatically assigns between one and five dock cranes to each vessel, as a function of number of lifts required to discharge and load the ship. If the ship is in a slip, it assigns twice the number of dock cranes, up to a maximum of eight. The user can adjust the dock crane assignment logic as needed.

The user specifies average travel distance from the wharf to the centroid of the storage area and the model assumes a hostler or straddle carrier travel speed of 15 miles per hour. The user also specifies the type of equipment used to receive from the vessel into the stacks and to deliver from the stacks to the vessel.

The model finds the number of lift equipment cycles for each ship call by taking the total number of moves per call and multiplying it by the percent of containers that are stored in stacks (grounded). For containers stored on wheels, the hostler brings a bare chassis to the dock crane where the container is loaded, and then it takes the chassis and container to the wheeled storage area and un hooks it. This does not require any work by lift equipment, but it does increase the cycle time of the hostler because it has to make an extra trip to get a bare chassis between moves.

4.3 Gate Operation

The model offers users a variety of options for studying different strategies to reducing truck traffic congestion so that the effects of these options can be quantified. The gate model reports the total number of trucks arriving at and departing from the terminal each day on an hourly basis. These trips are aggregated into different periods such as weekday morning rush hours, weekday evening rush hours, weekday non-rush hours, and weekends. This permits the analyst to assign different travel speeds for certain times of day depending on highway congestion.

To the extent that the terminal is grounded, the model takes the number of trucks departing with a load, and serves them with the lift equipment entered by the user. Trucks arriving with a load are also served by lift equipment, and all empties are handled by side-pick. This gives the total number of cycles for each lift equipment type required to serve the gate. Road trucks picking up or delivering a container on chassis do not require service by lift equipment.
A separate spreadsheet was created to analyze the road truck trips at the terminal (it is separate from the larger model only to keep file sizes manageable). This model is a multi-class, open queuing network with nodes representing all of the possible destinations for a road truck inside the terminal. The user assigns percentages for the likelihood of a truck to travel from one node to the next and the assumed service time at each node. The input to the model is the number of trucks arriving each hour.

The outputs of the road truck model are the average times spent waiting at the entry and exit gates, transiting the terminal, and waiting for service inside the terminal.

### 4.4 On-Dock Rail Operation

If the terminal has an on-dock rail yard, some containers arrive or depart the terminal via rail. The user specifies the percent of on-dock intermodal cargo. The user also specifies the length and number of working tracks and storage tracks. Then, based on the rail yard configuration (whether the yard has dedicated arrival and departure tracks or a runaround track), the model calculates the approximate number of trains per week of rail yard capability. This is compared to the number of trains per week required by the percent intermodal entered by the user. If the percent intermodal is too large for the capacity of the rail yard, the user is alerted with a message in red. The user either needs to increase the size of the rail yard or decrease the percent of on-dock intermodal.

The model distinguishes between “unit” trains and “block” trains. A unit train is one that is already complete and ready to be pulled by a long-haul engine. Block trains are smaller pieces of a train that need to be pulled elsewhere and combined with other block trains until they become a unit train. Block trains are pulled by switch engines. Long-haul engines and switch engines have different horsepower and emissions, so they have to be calculated separately. The model includes the long-haul engine emissions for the distance that it is within the Air Quality Management District. Switch engines are assumed to run the distance from the terminal to a train consolidation yard and back.

The equipment needed to strip and load the trains in the rail yard is also included in the model. A fleet of hostlers or straddle carriers drays containers between the container yard and the rail yard, and lift equipment (typically top-picks or RTGs) takes containers on and off the trains.

If the rail yard is a buffered operation, the user can enter the percent of moves that use the buffer. Buffers allow for a greater percentage of double-cycling for the dray vehicles, but those emissions may be offset by the lift equipment needed to take containers in and out of the buffer. An interesting application of the model would be to determine whether a buffer could decrease air emissions at a given terminal.

### 5. Conclusions

Air emissions considerations will increasingly influence port design and operations as regulatory controls become more widespread. Further, as port air emissions gain media attention, people with varied backgrounds and interests will join engineers in efforts to reduce harmful emissions related to port activities. These trends suggest the need for a
transparent modeling tool that can be used to quantify the emissions resulting from daily port operations.

The goal of developing this model is to integrate existing planning models into a comprehensive and convenient tool designed specifically for marine container terminals. The model is in spreadsheet format enabling users to understand how the model works without knowing any complex computer languages.

The model can estimate future emissions based on throughput as well as operating characteristics. It is designed to be useful for comparing and prioritizing different emissions reductions strategies.

To date, much of the effort on reducing port emissions has focused on the emission factors of equipment. Equipment modifications are required to improve emission factors (or rates of emission). However, equally important in controlling emissions is the time spent by different types of equipment in various modes. Improving efficiency by reducing the operating times with measures such as increased gate efficiency to reduce idling has a double benefit of improving terminal efficiency and reducing emissions. The integrated terminal model approach helps decision makers quantify both benefits and make informed decisions in regard to terminal operations and air quality improvements.