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Emissions reduction analysis of voluntary clean truck programs at US ports

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ABSTRACT

This paper analyzed three incentive-based, voluntary vehicle replacement programs underway at US ports using fleet baseline and program completion data and an emissions standard-based emission estimation methodology. The principal findings demonstrate that best management practices for voluntary clean truck programs can substantially reduce truck drayage emissions, although not to the level achieved through mandatory programs. Emissions reductions were found to be 1–4% as compared to potential reductions of 12–15% for particulate matter and 31–34% for nitrogen oxides.

1. Introduction

The freight transportation system that annually moves more than 37 million Twenty-foot equivalent units (TEUs) through US ports is largely powered by heavy-duty diesel engines, whose advantages include high performance and long life. The emissions from the concentrated number of engines operating at ports, however, are a significant contributor to poor air quality in adjacent communities and to exceedances of national ambient air quality standards (NAAQS). Exposure to diesel pollutants is a recognized health threat. As such, many ports have been called upon, some under threat of legal action, to implement pollution control efforts.

Emissions inventories conducted by ports consistently highlight drayage trucks as a significant contributor to port-related pollution, accounting for 25–43% of NOx emissions, in part because drayage trucks are typically older and more polluting than the average long haul truck. As a result, initiatives to modernize the drayage fleet have been a key element of many clean air plans at ports.

The Port of Long Beach and the Port of Los Angeles (POLA) have undertaken the most aggressive actions to reduce emissions from this sector, ultimately mandating the use of drayage trucks that meet the new 2007 emission standard. While the Southern California clean air plan was effective in reducing POLA truck emissions 80% from baseline emissions in one of the most heavily polluted areas of the country, program implementation was controversial and politically charged. In an effort to reduce emissions from port drayage trucks without regulatory action, some ports have opted to implement voluntary control efforts.

Given the adoption of emissions mitigation initiatives at ports and development of non-regulatory programs, this paper analyzed the effectiveness of emissions reduction efforts through voluntary clean truck programs in Virginia, Charleston, and Houston based on best management practices.

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Table 1
Heavy-duty highway CI engines – exhaust emission standards (modified).

Model year	NOx (*g/bhp-hr*)	PM (*g/bhp-hr*)
1985–1987	10.7	–
1988–1989	10.7	0.60
1990	6.0	0.60
1991–1993	5.0	0.25
1994–1997	5.0	0.10
1998–2003	4.0	0.10
2004–2006	2.375	0.10
2007–2009	0.2–2.375	0.01
2010	0.2	0.01

Notes: 2007–2009 was a phase-in period for the 2010 NOx standard; (–) represents no standard in place for given timeframe.

2. Methodology and data

This paper analyzed data from ongoing clean truck programs at the Port of Virginia, the Port of Charleston, and the Port of Houston Authority. These ports were selected due to their potential for high trade growth and their voluntary truck program design. The growth in throughput, attributed to rapid population growth and Panama Canal expansion in a recent report by the US Army Corps of Engineers, may lead to an increase in emissions at these ports and a greater need for pollution mitigation on the Gulf and east coasts (Institute for Water Resources, 2012). Although mandatory programs have resulted in significant emissions reductions, the success of voluntary programs has not been assessed.

To calculate emissions reductions from clean truck programs at the individual port level, we employed the US Environmental Protection Agency's (EPA) (2012) Heavy-Duty Highway Compression-Ignition Engines Exhaust Emissions Standards. EPA periodically revises emissions standards for trucks, and over the past two decades the agency has strengthened the standards dramatically, resulting in current model year trucks that are up to 60 times cleaner than many older models (Table 1). These standards are based on engine model year and not truck model year.

These standards, as well as funding requirements, local air quality needs, and emission reduction goals, have governed strategic decisions on the development of clean truck programs. A port interested in reducing NOx, for instance, might choose to optimize emissions reductions by replacing pre-1990 trucks with 2010 or newer trucks while programs designed to target PM reductions may choose to replace pre-1994 engines with 2007 or newer engines. A robust multi-pollutant strategy would emphasize retirement of pre-1990 engines coupled with the introduction of 2010-standard engines.

This paper utilized secondary data through May 2012, collected by the respective program administrators (the organization implementing the vehicle replacement program). Each program maintained a database that tracked applicants and included information such as vehicle identification number, application status, and vehicle model. Most program-reported emissions reductions calculations were driven by reporting requirements from funding agencies, which often employed their own data collection systems and methodology guidelines. For the purposes of this paper, however, a basic emission standard, conversion standard, and VMT (vehicle miles traveled) assumption of 50,000 per year were utilized to calculate combustion emissions. This did not include all emissions from operations, such as idling, due to data constraints and methodological variability in input estimations. This simplified methodology allowed for the measurement of trends in emissions rather than aggregate emissions and provided the ability to isolate the impact of vehicle replacement, as opposed to other factors that impact emissions such as idling.

The VMT assumption came from a 2009 drayage study that found average yearly VMT to be 55,336 (Harrison et al., 2009). However, the high degree of variance in VMTs and the skewed distribution of model year trucks operating at ports means that older trucks may run significantly more mileage than newer trucks and more accurate data is needed to fully understand the isolated effect of clean truck programs. From a policy perspective, the differences in business models between LMCs (licensed motor carriers) and IOOs (independent owner–operators) added to the complicated nature of the drayage industry and further demonstrated the need for clean truck programs to address market imbalances (Monaco and Grobar, 2004).

The most basic calculation used for estimating emissions is an activity-based method whereby emissions factor multiplied by activity is equal to the emissions generated:

$$\frac{g}{mi} \times mi \equiv g \tag{1}$$

where g/mi is a derived emissions coefficient given by Eq. (2), mi is a measure of activity (VMT) over a predetermined period of time (1 year), and g is the amount of emissions in grams.

The output represents the estimation for annual emissions generated by the operation of one drayage truck with engine of model year X. Although each pollutant and each model year engine have a specific emissions factor, the formula remains the same. Subtracting the emissions that the new fleet was expected to generate from the emissions that would have been generated by the old fleet, under the same circumstances, yielded the yearly emissions benefit from the vehicle replacement program. As trucks were expected to remain in service at the port for multiple years, emissions benefits calculated by program administrators were extrapolated out to a longer time horizon, often 5 or 7 years based on reporting requirements from a funding agency. Here, we employed a time frame of 1 year.

The emissions coefficient used in Eq. (1) was derived using the following equation:

$$\frac{g}{bhp-hr} \times \frac{bhp-hr}{mi} = \frac{g}{mi} \tag{2}$$

where $\frac{g}{bhp-hr}$ is the EPA emission standard, $\frac{bhp-hr}{mi}$ is the conversion factor, and $\frac{g}{mi}$ is the emissions coefficient.

As seen in Table 1, emissions standards were set based on grams of pollutant emitted per brake horsepower hour. A conversion factor from state regulatory agencies was applied to the engine standard to allow for a calculation of pollution emitted per vehicle per year. The EPA emission standards, VMT assumptions, and program data were applied to the formulas above to derive an emissions estimate.

Baseline emissions from each port were calculated by applying the simplified emissions estimation methodology to the existing drayage fleet inventory, prior to implementation of a clean truck program. This allowed a direct comparison between emissions reduced through the clean truck programs to those generated by a baseline fleet. Thus, the full fleet distribution was used instead of relying on average model years. The other comparison points were the potential emissions reductions available if all trucks of certain years were replaced; a 100% participation rate. The emissions inventory conducted by each port involved multiple factors and did not isolate the impact of vehicle replacement. The analysis measured only the effect of vehicle replacement, all other factors considered equal. While many other factors are known to impact emissions, such as container throughput and variation in VMTs, these variables were not assessed because of the potential for multiplier effects that would have distorted the direct impact of vehicle replacement.

3. Case studies

3.1. Virginia green operators program (GO)

The Virginia Port Authority's 2010 carrier survey identified the top 125 carriers and surveyed them for their fleet information, including the age of their trucks. Although a truck-by-truck database was not available, the process found a truck fleet of 2500 frequent callers with 7% of them 1993 model year or older, 24% 1994–1998, 42% 1999–2003, and 27% 2004 or newer. Eighty-three trucks were replaced in the GO program, with an average "new truck" year of 2007 and "old truck" year of 1996 (Table 2). Considering that only 27% of the fleet was 2004 or newer at the time of the survey, the replacement trucks with average model year of 2007 modernized the fleet. While the 11-year delta represents significant pollution reduction in terms of advancements in emissions regulations, only 3% of the truck fleet has been replaced.

Table 2
Comparison clean truck program replacement data.

	Norfolk	Charleston	Houston
Truck program			
Baseline truck fleet size	2500	2606	3050
Number of trucks replaced	80	29	49
Avg. MY of retired engine	1996	1992	1997
Avg. MY of replacement engine	2007	2005	2009
Avg. difference in years	11	13	12
PM			
Emission standard change avg. retired engine to avg. replacement engine	0.10–0.01	0.25–0.10	0.10–0.01
Emissions reduced per truck per year (g)	19,653	29,847	15,794
Emissions emitted per replacement truck per year (g)	2266	14,050	1420
Yearly tons reduced	1.73	0.95	0.85
Reduction as percentage of baseline emissions	3.5%	2.7%	1.4%
Potential reduction 1 (pre-1994 to 2007+) as % of baseline	24.7%	33.6%	31.9%
Potential reduction 2 (pre-2007 to 2007+) as % of baseline	91.9%	92.1%	92%
NOx			
Emission standard change avg. retired engine to avg. replacement engine	5.0–0.2	5.0–2.4	5.0–0.2
Emissions reduced per truck per year (g)	682,068	575,273	677,499
Emissions emitted per replacement truck per year (g)	50,895	365,428	30,300
Yearly tons reduced	60.15	18.39	36.59
Reduction as percentage of baseline emissions	3.6%	1.0%	1.79%
Potential reduction 1 (pre-1994 to 2007+)	12.8%	18.2%	14.9%
Potential reduction 2 (pre-2007 to 2007+)	95%	95.1%	95.2%

3.2. Charleston seaport truck air cleanup southeast program (STACS)

South Carolina State Ports Authority (SCSPA) utilized their yard management system to establish a baseline for their truck program. Based on an internal data review from fall 2009 to fall 2010, 2,600 trucks entered the port at least 52 times. These frequent users accounted for 90% of the gate entries over the period and were considered the truck fleet population at SCSPA; 10% of the trucks were model year 1993 or older, the retirement goal for the truck program. Twenty-nine trucks of average model year 1992 have been replaced through STACS with trucks of average model year 2005.

3.3. Houston Drayage Loan Program (DLP)

The Houston DLP combined a traditional grant program from state funds tied to NOx reductions with low-interest loans from federal funds for drivers seeking to replace their vehicles. The grant program awarded money, not on a flat per truck basis as did other programs, but rather on an emissions reductions basis. Reductions were calculated using a number of variables, including the age of the truck to be replaced and the age of the truck to serve as the replacement. This highly incentivized the oldest trucks to be taken off the road and replaced with the newest vehicles. The program did not require retired trucks to be pre-1994, but the best incentives were given to those with the greatest potential to reduce pollution. The loan package was dependent on the credit profile and not on emissions reductions. Forty-nine trucks replaced through the Drayage Loan Program had an average "new truck" model year of 2009 and an average "old truck" model year of 1997.

4. Results

Comparing program reductions to estimated baseline emissions, this study found that all three programs have achieved reductions for both PM and NOx of 1–4% to date. However, these results should be interpreted in the context of potential reductions or theoretical full-scale replacement. The potential reductions represented the best possible emissions outcomes if all pre-1994 engines were replaced with 2010-standard or newer engines (a standard goal or interim benchmark for many clean truck programs) or if all 2006 or older engines had been replaced, as in Southern California, with 2007 or newer engines. As seen in Table 2, Virginia reduced 3.5% of baseline PM emissions. If the GO program were to replace every pre-1994 engine with a 2007 or newer engine, referenced here as potential reduction 1, only a 24.7% reduction from baseline would be realized. Potential reduction therefore established a type of ceiling for clean truck programs.

Reaching the Southern California target of a purely 2007 or newer drayage fleet would enable these voluntary programs to achieve over 90% emissions reductions from baseline. Emissions reductions of this magnitude, however, would require a much more intensive investment and implementation plan than current voluntary programs. At existing funding levels and program methodologies, emissions reductions of 1–4% may be better understood in the context of 24–34% potential PM reductions and 12–19% potential NOx reductions.

In comparing NOx pollution reduction effectiveness, Virginia and Houston had nearly identical outcomes of 0.75 and 0.74 tons of NOx reduced per truck per year, while the Charleston program reduced 0.63 tons of NOx per truck per year. This was expected based on the differences in engine emissions standards from the average age of "old" and "new" trucks for each program. Charleston did not introduce trucks with the most stringent emission standard for NOx of 0.2 *g/bhp hr*, and therefore did not achieve the same pollution reduction effectiveness as Virginia or Houston.

While Virginia and Houston had similar levels of pollution reduction, overall per truck emissions were higher in Virginia due to the slightly older age of "new trucks" there, as evidenced in Table 2. In Houston, the new truck fleet was calculated to emit an average of 30,300 g of NOx per truck per year compared to 50,895 g in Virginia and 365,428 g of NOx per truck per year in Charleston. Again, this could be explained by the relatively old age of trucks introduced in South Carolina.

In comparing PM pollution reduction effectiveness, Charleston reduced the most PM pollution at 0.033 tons per vehicle per year. This was relatively high due to the age of trucks retired there. Virginia's reductions of 0.022 tons per vehicle and Houston's reductions of 0.017 tons per vehicle were understandably similar due to the comparable age profile of trucks retired and replaced. Houston would need to retire a greater number of older trucks to improve its PM emissions reductions effectiveness.

The results of this analysis match the expected outcome in terms of the goals and guidelines for the respective programs: The Houston area is in nonattainment for ozone, thus the clean truck program targeted NOx (a precursor of ground-level ozone), resulting in the second-highest NOx emissions reduction effectiveness (emissions reduced per truck) and lowest level of overall NOx emissions (emissions emitted per replacement truck) of the programs evaluated. In Charleston, the focus on PM emissions led to targeted retirement of pre-1994 trucks since PM engine standards were strengthened beginning with model year 1994 engines, resulting in the largest PM reductions per truck replaced of all three programs.

5. Conclusions

Ports are high-risk areas for adverse air quality and public health outcomes due to highly concentrated transportation and industrial activity, equipment age significantly older than industry standards, as well as proximity to environmental justice communities. As such, clean truck programs have established themselves as a common tool to reduce harmful emissions at

US ports. Though widespread, these programs vary significantly across the country. This paper attempted to characterize the effectiveness of voluntary programs and the analysis is particularly urgent as the industry anticipates container throughput at ports with voluntary programs to substantially increase over the coming years. Our principal findings were that programs in Virginia, Charleston, and Houston reduced emissions by 1–4% in the context of potential reductions of 12–34% using a traditional benchmark for voluntary programs. While these reductions cannot be compared directly to figures from mandatory programs, the voluntary programs surveyed were dramatically less effective in reducing emissions than the mandatory clean truck programs implemented at the ports of LA and Long Beach. Pollutant focus and model year incentives and restrictions greatly influenced both emission reduction and emission output performance. Emission reduction effectiveness can be improved through optimization of truck replacement to retire the oldest engines in service.

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