Title: Impacts of Idling Reduction Devices on Transit Buses: A Preliminary Analysis

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Abstract: As the harmful health and environmental effects of diesel particulate pollution are brought to light, much attention has been paid to reducing tailpipe emissions from diesel vehicles. While there are numerous ways to reduce harmful diesel tailpipe emissions—reducing sulfur in fuel, installing exhaust after-treatment technologies, and replacing or rebuilding engines, for example—one of the most direct methods is to reduce fuel consumption by curtailing unnecessary idling.

Urban transit buses idle for many reasons. The most common form of idling is unavoidable: idling in traffic. This paper asserts that many transit buses also idle unnecessarily—when warming up in the morning, waiting at turn-arounds, and loading and unloading passengers at terminal stops—and that many of these hours of bus idling can be avoided through the means of technology.

In recent years, the trucking industry has been using idling reduction (IR) devices to limit the amount of time engines need to run while vehicles are stationary. A number of these devices could work well in a transit bus application. Direct-fired heaters, auxiliary power units (APUs), battery-powered units, and automatic shutdown-startup systems can be installed aftermarket to maintain comfortable cabin temperatures without having to keep a bus's engine running. These devices could eliminate up to 95% of fuel consumed per hour of bus idling.

This paper explores the application of idling reduction devices to Chicago Transit Authority buses to quantify agency benefits such as fuel savings, reduced maintenance, and increased engine life, and public benefits such as reductions in particulate matter and oxides of nitrogen and their associated public health effects.

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Introduction

As the prevalence of asthma increases and greater attention is paid to global climate change caused by vehicle emissions, reducing tailpipe pollution from diesel vehicles has become a greater priority for public health and environmental advocates and policymakers. Diesel vehicles are primary sources of two pollutants monitored by the US Environmental Protection Agency's (US EPA) National Ambient Air Quality Standards (NAAQS): NOx (oxides of nitrogen) and PM (particulate matter, which includes PM10 and PM2.5, coarse and fine particles, respectively).

On-road sources such as trucks and buses contribute as much as 66 percent of the PM10 from fuel combustion (American Lung Association 2000). Diesel engines are also primary contributors to NOx (which includes NO_2 and N_2O) pollution, producing 26 percent of the NOx from on-road sources and about 20 percent of the total NOx in ambient air (Philadelphia Diesel Difference 2008). Despite these contributions, heavy-duty trucks and buses comprise only 5% of the total number of vehicles on the roadways (Clean Air Task Force 2005).

Why should we be concerned about NOx and particulate matter? Both are responsible for a host of public health and environmental problems.

- NOx and volatile organic compounds (VOCs) react in the presence of sunlight to form ground-level ozone (O_3), another pollutant monitored by the NAAQS, and a pollutant which can inhibit lung function.
- Nitrous oxide (N_2O) is a greenhouse gas which contributes to global warming.
- NOx reacts to form nitrate particles and acid aerosols, which can cause respiratory problems.
- NOx contributes to the formation of acid rain.
- NOx contributes to nutrient pollution that breeds algae and deteriorates water quality.
- NOx contributes to atmospheric particles which cause haze (US EPA 1998).
- PM has been linked to increased hospital admissions for respiratory diseases, chronic obstructive pulmonary disease (COPD), pneumonia, heart disease and premature death (US EPA 1997).
- PM contributes to atmospheric particles which cause haze (US EPA 2007c).
- Particles travel before settling on ground or in water. Once settled, PM can turn lakes and streams acidic, contribute to eutrophication in waterways, deplete nutrients in soil, and damage crops.

While there are numerous ways to reduce harmful diesel tailpipe emissions—reducing sulfur in fuel, installing exhaust after-treatment technologies, and replacing or rebuilding engines, for example—one of the most direct methods is to reduce fuel consumption by curtailing unnecessary idling. While state and local anti-idling laws sprout up around the country to limit pollution from heavy-duty trucks and school buses, the federal government has focused their efforts on (often voluntary) programs to limit idling from trucks and freight trains. In most cases, state laws and programs have exempted transit and coach buses because they are considered to be in motion for the majority of their use.

Most transit bus idling occurs while a bus is stuck in traffic or making a stop along its route. There are, however, some scenarios in which transit buses idle unnecessarily, and despite the fact that many solutions exist to limit idling from these buses, these solutions have not garnered much interest from transit agencies, researchers or lawmakers. This paper will review the causes and effects of transit bus idling, and will examine the potential costs and benefits of employing idling reduction technologies on Chicago Transit Authority (CTA) buses to limit fuel consumption and pollutant emissions.

Background

Health Effects of Diesel Emissions

Over six million children in the U.S. under the age of 18 live with asthma, and the numbers continue to rise: Between 1980 and 1994, the prevalence of asthma increased 75% (Centers for Disease Control 1998). For children with asthma, poor air quality—and soot in particular—means more than unsightly haze; it can exacerbate breathing problems, forcing children to miss school and increasing the potential for hospitalization. Asthma is a primary cause of hospitalizations in children under 15 and the most common cause of school absenteeism for chronic conditions (American Lung Association 2007). The US EPA states that "infants and children could have a greater susceptibility to the acute/chronic toxicity of DPM [diesel particulate matter] because of their greater breathing frequency and consequent potential for greater particle deposition in the respiratory tract, which has not reached full development" (US EPA 2002). Among other public health and environmental concerns, the discovery that diesel exhaust is a likely human carcinogen (US EPA 2002) has contributed to an upswing in diesel emissions reduction programs.

Diesel-Related Pollutants

Diesel emissions are a mixture containing hundreds of organic and inorganic elements in two phases, the gas phase (which contributes to "smog," acid rain, and greenhouse gases) and the particle phase ("soot"). The specific composition of diesel exhaust varies by engine type (heavy vs. light duty), engine age, fuel used (low vs. high sulfur), operating conditions (acceleration, deceleration, idling, uphill and downhill runs) and vehicle load. For the purposes of study, assume that a 10-liter engine found in a "typical" transit bus consumes one gallon of fuel per hour idling, emitting 135 g/hr of NOx and 3.68 g/hr of PM (Behrentz et al 2004; US EPA 2007d).

Particulate Matter

Nearly all diesel exhaust particles are less than 10 micrometers in diameter (PM10, or "coarse particles"), while almost 94% are less than 2.5 micrometers (PM2.5, or "fine particles"), and 92% are smaller than 1 micrometer ("ultrafine particles"). Sources of PM2.5 are fossil fuel combustion from motor vehicles (gasoline exhaust emits far fewer particles than diesel exhaust), power plants, and wood burning and from some industrial processes and incineration. Because of the nature of their sources, the chemical composition of PM10 varies considerably from that of PM2.5.

Diesel particulate matter concentrations range from 1-20 $\mu g/m^3$ in ambient outdoor air, depending upon sampling location and methods. The primary National Ambient Air Quality Standard set by the US EPA for PM is 15.0 $\mu g/m^3$ for annual measurement (arithmatic mean) and 35 $\mu g/m^3$ for any 24-hour period. Chicago, Cook County and the surrounding area (DuPage, Kane, Lake, McHenry and Will counties, as well as townships in Grundy and Kendall counties) that make up the Chicago region are classified as being in nonattainment for two pollutants: PM 2.5 and ground-level ozone.

While both particulate matter and gaseous emissions are suspected carcinogens, particulate matter should be analyzed separately from gaseous emissions because of the particularly hazardous behavior of particles. Coarse, fine, and ultrafine particles can evade respiratory defenses and embed themselves deep in the lungs. A number of studies performed over the past 20 years have found that particulate matter hinders lung function, aggravates respiratory illnesses such as bronchitis and emphysema, and is associated with premature death (Dockery 1993).

Gaseous Emissions

In addition to particulate matter, diesel exhaust is responsible for a number of hazardous gaseous emissions. Diesel exhaust gases include those formed from combustion (nitrogen, oxygen, carbon dioxide and water vapor) and from incomplete combustion (benzene, formaldehyde, 1,3-butadiene, and polycyclic aromatic hydrocarbons) (Wargo et al. 2002). Gases are delivered to the lungs with the help of particulate matter, which acts as a vehicle for transfer. Recent studies have found that the respiratory responses associated with diesel exhaust are not solely a function of the diesel particles, but are also affected by the toxic organic compounds contained in the gaseous phase of the diesel exhaust (Hiura 1999).

Benzene, 1,3-butadiene, formaldehyde, acetaldehyde, naphthalene, PAHs, and nitroarenes—all chemicals found in diesel exhaust—are among those classified as “known” or “reasonably anticipated to be” human carcinogens by the US Department of Health and Human Services (US Department of Health and Human Services 2005). Many other chemicals in diesel exhaust are listed by the California Air Resources Board as toxic air contaminants. In 1998, the State of California Scientific Review Panel on Diesel Exhaust concluded: “A level of diesel exhaust exposure below which no carcinogenic effects are anticipated has not been identified” (California Scientific Review Panel 1998).

Current Policy

Anti-idling legislation, programs and funding exist at all levels of government. At the federal level, the EPA awards grants to diesel emission reduction programs (including idling reduction and diesel retrofit programs) across the country through the National Clean Diesel Campaign; for fiscal year 2008, the amount of funding available is $49.2 million (US EPA 2007b). Since 2000, EPA has funded several demonstration projects through this program, but these projects have been limited to trucking or freight rail despite the fact that any regional, state, local, tribal or port agencies with jurisdiction over transportation or air quality may apply.

Idling (particularly school bus idling) has also been a focus of state and local policymakers in recent years. As of 2006, 31 states have anti-idling laws, although transit buses are often exempt from anti-idling laws or have longer idling time allowances in many states (transit buses are exempt from Illinois Public Act 094-0845, Excessive Idling). The Illinois Board of Education and regional school superintendents are allowing individual school districts to decide whether to order reduced bus idling or to direct funding toward purchasing cleaner equipment.

In August 2005, the City of Chicago introduced the Vehicle Idling Management Policy, requiring that drivers of the 7,500 municipal vehicles cannot allow vehicles to idle for more than five minutes in any 60-minute period (City of Chicago 2005). Enforcement of this policy increased in 2007-8 through the installation of idle-shutdown devices on 500 trucks, which are monitored for compliance using Global Positioning System (GPS) technology (City of Chicago 2008).

Idling Reduction Devices

The trucking industry has been using idling reduction devices such as direct-fired heaters, auxiliary power units, battery-powered heating/AC and automatic shutdown-startup systems for a number of years, but each has its drawbacks. While all of the devices provide fuel savings, transit agencies must minimally consider the technology cost, size and weight when selecting a solution. Table 1 compares four common on-board idling reduction technologies currently used in freight trucking, but transferable to a transit bus application.

Table 1. On-board Truck Idling Reduction Technologies

Idle Reduction Technology	Function	Pros	Cons	Cost of Unit, installed	Fuel Use (gal/hr)
Direct-fired heater	Heating for cabin and/or engine.	Can be used at any stop for heating. Small and lightweight.	Cannot provide cooling. Requires battery power and may be unreliable when not equipped with automatic engine starting.	$3,200	0.04-0.16
Auxiliary power unit (APU)	Heating and air conditioning of cabin, heat for engine, and power for auxiliaries.	Can be used at any stop for heating, cooling, and auxiliaries. Recovers waste heat for space heating.	Heavier and larger than direct-fired heater. May require separate air conditioner.	$7,095	0.08-0.3
Battery-powered heating/AC	Heating and air conditioning of cabin.	Provides all needs, zero emissions.	Heavy.	$7,000-8,000	0-0.17 (depending on configuration)
Automatic Shutdown/Startup Systems	Controls the engine (start and stop) based on a set time period or on ambient temperature, and other parameters (such as battery charge).	Low cost. Available from engine manufacturer.	Low driver acceptance.	$1400-4000	0.15-0.40

Source: Turchetta 2005

A direct-fired heater can be used to heat the cabin and the engine simultaneously or each separately. A major advantage of the technology is that it can often operate for over twenty hours on one gallon of diesel fuel. One major disadvantage, however, is that they cannot provide air conditioning, and are therefore only useful in winter months.

More sophisticated than direct-fired heaters, auxiliary power units, or APUs, are units that—depending on size—may be mounted internally or externally to the vehicle. An APU consists of a 5-10 horsepower diesel engine with a cooling system, heating system, and generator or alternator (US EPA 2006). While useful to truck drivers who often idle their vehicles overnight, bus operators may find less need for electricity to run appliances. Considering their weight (over 300 pounds) and cost (upwards of $7000), APUs may not be ideally suited for transit applications.

Battery-powered heating/AC units can supply up to 10 hours of power (depending on the battery voltage, typically between 6-12 volts) for air conditioning and heating using a battery pack which recharges using the vehicle's alternator. Like auxiliary power units, battery-powered systems may be prohibitively heavy (between 200-500 pounds) and expensive (about $7000) (Turchetta 2005, US EPA 2006).

An automatic shutdown-startup system is an electronic component that monitors the temperature inside and outside the bus to automatically start the engine, increase engine speed for maximum efficiency, heat or cool the cabin, and shut the engine off. Although the features vary by manufacturer, many have different modes of operation. Under "engine mode," if engine oil or battery voltage drops below a set level, the engine is automatically started. Under "cabin comfort mode," a thermostat starts and stops the engine to maintain the desired temperature. Under "mandatory shutdown mode," the engine will shut down after a set number of minutes (Cummins 2007). Smaller than a laptop computer screen and weighing less than 30 pounds, the devices could fit seamlessly into the interior of many buses, and at a cost ranging from $1,375 to $3,750 per device, the controls could pay for themselves in fuel savings in a matter of years.

Case Studies

In 2007 and 2008, CTA was awarded $517,200 and $648,000 (respectively) in CMAQ (Congestion Mitigation and Air Quality) money to partially fund installation of over 250 bus battery defibrillators. The defibrillators are being used in cold weather to jump-start bus batteries used to power engine pre-heaters at the two outdoor bus garages (Chicago Metropolitan Agency for Planning 2008). These engine pre-heaters reduce bus warm-up times at both outdoor garages and could potentially be used to heat the cabin while keeping the engine shut off when loading and unloading passengers during the winter months. Further research into bus operations and idling behavior is required to determine if the technology could be used to a greater extent or in conjunction with another technology.

In 2005, the Maryland Transit Agency (MTA) employed and enhanced bus automatic shutdown-startup devices using a Clean Cities grant awarded by the Department of Energy. The Maryland Department of the Environment and the MTA retrofitted 100 buses with Clever Devices BusLink Switches, which allow "just-in-time" engine warm-up. The switches automatically activate engine pre-heaters that heat the engine coolant and allow the vehicles to be at operating temperature when started in the morning. A wireless communication system was also installed to allow the MTA to remotely operate the devices (US Department of Energy 2006).

CTA Bus Fleet Profile

Table 2. CTA Bus Fleet Profile

Vehicle Type	Fleet Name	Active Vehicles			Future Vehicles		
		Total	Minimum Year	Maximum Year	Total	Minimum Year	Maximum Year
Standard Bus (40 ft)	6400 Series Nova	484	2000	2002			
Standard Bus (40 ft)	4400 Series TMC*	240	1991	1991			
Standard Bus (40 ft)	1000-series New Flyer	1030	2006	2006			
Diesel-Electric Hybrid Bus (40 ft)	800-series New Flyer	10	2006	2006			
Diesel-Electric Hybrid Bus (40 ft)	900-series New Flyer	10	2007	2007			
Standard Bus (40 ft)	6000 Series Flxible	330	1995	1995			
Articulated Bus (60 ft)	7500 Series NABI Artic.	226	2003	2005			
Standard Bus (40 ft)	5300 Series Flxible*	96	1991	1991			
Standard Bus (40 ft)	5800 Series New Flyer*	60	1995	1995			
Short Bus (<40 feet)	Optima Opus 30ft	45	2006	2006			
Articulated Bus	600-series New Flyer				150	2008	2008
TOTAL		2531			150		

Sources: Regional Transportation Asset Management System (RTAMS), ChicagoBus.org, TransitChicago.com
* entire fleet due to be retired by December 2008

The CTA currently operates a fleet of 2,531 buses, including 226 articulated 60-foot buses and twenty 40-foot diesel-hybrid electric buses. By year-end 2008, the agency expects to phase out the remaining 396 model year 1991 and 1995 buses and replace them with 150 new articulated 60-foot buses by summer 2009 (CTA 2008). All of the CTA's buses are Americans with Disabilities Act (ADA) compliant.

CTA Bus Idling Behaviors

Using the Chicago Transit Authority bus fleet to illustrate the effects of idling reduction technologies on urban transit buses, assume that the average CTA conventional ultra-low sulfur diesel (ULSD) bus burns one gallon of fuel per hour idling. Considering time spent idling at terminals (particularly the two outdoors[1]), maintenance shops, turn-arounds, and on emergency breaks, a bus that is in service for 50 hours per week may idle for four of those hours. Multiply that fuel usage times the size of the CTA's current non-hybrid bus fleet (2,511) and it adds up to over 10,000 gallons burned per week—at the current price of diesel fuel ($3.30 per gallon), that's a cost of $33,150 per week or $1.72 million per year. Factoring in engine wear-and-tear, increased maintenance costs, and the public health and environmental effects of all those buses getting 0 mpg, and the costs rise.

Even assuming that all idling at transit facilities is necessary and minimal, buses idle—often avoidably— when queuing at special events. At the conclusion of any Cubs game at Wrigley, boat show at McCormick Place, or concert at the United Center, many CTA buses can be found lined up waiting to load passengers, their engines running, even in comfortable outdoor temperatures which don't require the use of cabin heating or air conditioning. The CTA operates six "special" routes specifically to serve tourist attractions and sports venues; these routes should be examined separately from key and support routes to determine if they experience higher rates of idling and—for those routes which only operate during certain months of the year, such as the 154 Wrigley Field Express—if their contributions to the overall idling problem are negligible.

Why do drivers leave their engines running even in comfortable outdoor temperatures? In studying truck drivers, the EPA found that habit and myth play a large role. If drivers have never been told to shut off their engines when loading or unloading passengers, there is no reason for them to do it on their own; they may also fear being reprimanded for atypical behavior. Long-haul truck drivers were taught not to turn off a diesel engine for fear it would not restart. While there may be some need to do this with much older engines, it is not necessary with modern engines. Similarly, many people erroneously believe that restarting a hot engine emits more pollution than idling continuously (US EPA 2007a), and that idling causes significantly less wear on internal parts compared to driving at regular speeds (US EPA 2007b).

There are both behavioral and technological solutions to minimize avoidable idling. Drivers can learn to separate myth from fact, and can be trained to shut off their engines after a certain number of minutes or after the cabin reaches a comfortable temperature. Behavior, however, may be difficult to change and policies even harder to enforce. Technological solutions exist that may help to reduce all forms of idling without concern for the behavioral causes.

[1] CTA operates eight bus terminals, of which two (Forest Glen and North Park) are outdoors.

Conclusions

Further research into the applicability of idling reduction technologies to urban transit buses is required before a particular technology can be recommended. The next step in this research is to better understand bus operator behavior. At a minimum, the following questions must be answered in order to perform any alternatives analysis:

- How many hours per week does each bus idle?
- What are the factors affecting how much time the bus idles?
- What prevents a bus operator from shutting off the bus engine when stopped for more than a few minutes?
- In what situations does the bus operator shut off the bus engine?

Other quantifiable data needs to be gathered, including:

- Average idle time per week for each bus type in different weather conditions
- Cost of fuel per gallon
- Fuel economy for each bus type
- Cost of wear-and-tear on engine for each time increment of idling
- Cost of maintenance per hour
- Time between oil changes
- Engine overhaul cost
- Time/mileage between engine overhauls or life of buses

These values, along with behavioral survey responses from bus operators, will be critical inputs for performing the cost-benefit analysis required to select the appropriate idling reduction technology and for determining how policy-based and technological solutions to idling can fit together.

There are numerous methods available for performing a cost-benefit analysis for aftermarket bus technologies. The Argonne National Laboratory of the U.S. Department of Energy has created an idling reduction savings calculator (Argonne National Laboratory 2004) that will determine overall savings per year and "payback time" for each device based on inputs such as:

- How many hours per week do you idle your vehicle?
- How much do you pay for fuel?
- What is your idling fuel use?
- How much does an oil change cost you?
- How much fuel does the device use per hour?
- What is the maintenance cost per device?
- Percent of idle hours you would use the device (0-100)?
- What is the installed cost of the device?

The web-based calculator provided by the US EPA's SmartWay Transport Partnership (US EPA 2008) offers a fleet owner six idling reduction technologies to choose from, with the option to combine more than one technology in the same calculation. While the required inputs are similar to those for the Argonne calculator, the US EPA calculator also provides default prices for each technology, and an interface which allows a fleet owner to easily adjust variables such as fleet size, fuel use, fuel cost, and loan data.

A methodology must also be chosen for performing an environmental analysis. Options include comparing actual NOx and PM concentrations emitted by type of bus/model year before technology implementation to theoretical reductions in concentrations, source apportionment based on ambient data, EPA MOBILE6 and PART5 emissions models, and others. Once an environmental analysis is performed, public health effects could be extrapolated to determine the benefits of reduced idling to bus drivers and those who live on or near CTA bus routes.

The CTA is making great strides in “greening” their bus fleet. By 2009, nearly 10% of the fleet will be diesel-electric hybrid buses. More than half the buses in the fleet will be equipped with particulate filters. All are operating on ultra low sulfur diesel fuel. Still, there is room for improvement. As part of “The Future of CTA” initiative, the CTA is looking for ways to make their operations energy-efficient and environmentally sustainable. Installing idling reduction technologies fleet-wide would be an ambitious project for the CTA’s five-year plan and could go a long way towards saving money, fuel, and our region’s air.

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