AN ANALYSIS OF SCHOOL BUS IDLING AND EMISSIONS

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AN ANALYSIS OF SCHOOL BUS IDLING AND EMISSIONS

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LIST OF ABBREVIATIONS

AC .... Air Conditioning

AmTran .... American Transportation Corporation

APU .... Auxiliary Power Unit

ARRA .... American Recovery and Reinvestment Act

BenMAP .... Environmental Benefits Mapping and Analysis Program

CARB .... California Air Resources Board

CCSD .... Cobb County School District

CCV .... Closed Crankcase Ventilation

CO .... Carbon Monoxide

CO_2 .... Carbon Dioxide

DEQ .... Diesel Emissions Quantifier

DERA .... Diesel Emission Reduction Act

EPA .... Environmental Protection Agency

EPD .... Environmental Protection Division (of Georgia)

FTA .... Federal Transit Administration

GIS .... Geographic Information System

GPRS .... General Packet Radio Service

GPS .... Geographic Positioning System

GSM .... Global System for Mobile Communications

FHWA .... Federal Highway Administration

Georgia Tech .... Georgia Institute of Technology

GVWR ....Gross Vehicle Weight Ratings

HC ....Hydrocarbons

HDD...Heavy-Duty Diesel

HDDV ....Heavy-Duty Diesel Vehicle

HDDV-MEM ....Heavy-Duty Diesel Vehicle – Modal Emissions Model

IC Bus ....Integrated Coach Bus

ID ....Identification

I/M... Inspection and Maintenance

IMEI...International Mobile Equipment Identity

LED...Low Emission Diesel

MARTA ....Metropolitan Atlanta Regional Transit Authority

MPG.. Miles per Gallon

MOVES..MOtor Vehicle Emissions Simulator

NATA ....National Air Toxics Assessment

NCDC ....National Clean Diesel Campaign

NEI.. National Emission Inventory

NO_x ....Oxides of Nitrogen

OBD ....On-Board Diagnostic

OTAQ .... Office of Transportation and Air Quality

PAH...Polycyclic Aromatic Hydrocarbons

PEMS .... Portable Emission Measurement Systems

PERE..Physical Emission Rate Estimator

PM...Particulate Matter

SIM ....Subscriber Identity Module

SIP..State Implementation Plan

SPSS.. Statistical Packages for the Social Sciences

STP.. Scaled Tractive Power

TTI .... Texas Transportation Institute

ULSD .... Ultra-Low Sulfur Diesel

VMT...Vehicle Miles Traveled

VSP ....Vehicle Specific Power

SUMMARY

In 2009, Cobb County School District (CCSD) and Georgia Institute of Technology (Georgia Tech) received a competitive federal grant to implement an idle and tailpipe emission reduction program in the CCSD bus fleet. The project is designed to reduce school bus idling by installing GPS and idle detection systems in the bus, providing bus dispatchers with a web system to track vehicle activity and idling in real-time, and to automatically shut off the engine when idle thresholds at specific locations are exceeded. A team of Georgia Tech researchers is implementing the anti-idle program and estimating the emissions and fuel savings from the project using approved modeling methods. This thesis presents the results of the emission modeling process, as well as an analysis of baseline school bus idling activity.

EPA's MOVES mobile source emission model was used to develop emission rates for school buses for each operating mode, which are defined by the instantaneous vehicle speed, acceleration and scaled tractive power. Local data for Cobb County and Atlanta were collected and input into the MOVES model. The pollutants modeled include carbon dioxide, carbon monoxide, particulate matter (coarse and fine), oxides of nitrogen, and gaseous hydrocarbons. The vehicle activity data collected through the GPS and communications equipment installed in the buses were classified into the operating mode bins for each second of recorded data, and multiplied by the corresponding emission rate to determine the total modal emissions before and after project implementation. Preliminary results suggest that thousands of gallons of diesel fuel and thousands of dollars can be saved with the project, improving overall fleet fuel efficiency by 2%, as well as reducing emissions in some categories by as much as 49%.

CHAPTER 1

INTRODUCTION

1.1 Emissions and Idling of School Buses

Every day, nearly half a million school buses carry over 24 million children to school. Most buses are powered by diesel engines that pollute the air around them as well as inside the bus. Particulate matter (PM), oxides of nitrogen (NO_x), and carbon monoxide levels can build inside the buses during operation when ventilation is not optimal. The pollution level inside the bus can be as much as five times higher than the outside air (Environmental Defense Fund, 2006). Older buses tend to emit more than newer buses. EPA's new vehicle certification standards and natural vehicle fleet turnover due to retirement of older vehicles leads to high-emitting vehicles being replaced with cleaner new vehicles. Many school bus operators around the country are also pushing to retrofit older, higher polluting buses with emission reduction devices such as tailpipe and crankcase filters. Breathing diesel exhaust fumes increases the risk of cancer, heart and lung disease, asthma, and allergies (especially in children). Hence, there is a natural desire on the part of school districts to clean up their fleets.

Emission rates of heavy-duty diesel vehicles (HDDVs) are known to vary as a function of a number of different factors, including ambient weather condition, engine maintenance condition, vehicle age, engine warm-up status (cold-start or hot-starts), and most importantly, operating mode. The operating mode of a HDDV or school bus depends on the vehicle's speed, acceleration, road grade, accessory use, drag and rolling resistance, and ambient conditions. A common measure used is engine power in braking horsepower (bhp). For most pollutants, a vehicle operating at high speed and a heavy engine load, such as hard acceleration on an uphill grade, produces an emission rate that is much higher than cruising down a hill.

Idling activity emits CO, VOCs, NO_x and diesel particulate matter, sometimes at a higher rate than during general operation. Most idling is preventable and unnecessary; creating pollution that could be avoided through idle reduction measures. Thirty seconds of idling can use more fuel than turning off the engine and restarting, debunking the common myth that it is better to keep the engine running than to shut off and restart it later (EPA, 2011). "Idling gets you nowhere" and "Idling = 0 MPG" are catch-phrases that have been used in idle-reduction programs.

The purpose of school buses is to transport children to and from school and other locations; once that purpose is served, continued engine operation is needless, wastes fuel and money, and produces emissions. One hour of idling typically burns 0.5 – 1.0 gallons of fuel across a range of ambient weather conditions (Hearne, 2003). Idling for 10 minutes uses as much fuel as traveling five miles (EPA, 2011). One gallon of fuel produces about 20 pounds of CO_2, a major contributor to climate change. A gallon of fuel weighs about 6 pounds, but when burned and combined with oxygen from the atmosphere, the heavier molecules add about 14 pounds to the total weight.

School buses idle in the morning and afternoons before the scheduled bus routes begin, waiting at schools, maintenance yards, parking lots, and other locations. The causes of idling include cabin temperature control (heating), concerns about restarting the bus, lack of driver education, convenience, and in some cases, misinformation and instructions to idle the bus when stopped. Techniques aiming to reduce school bus idling and emissions include: idle reduction policies, real-time vehicle tracking, retrofitting vehicles with a range of emission control technologies, and replacing older, higher-emitting buses with new buses that follow more stringent EPA emission regulations.

Idle reduction retrofit options include auxiliary power units (APUs), direct fired heaters, and automatic engine shut-down. Emission control options include diesel particulate filters (DPF), partial flow-through filters, crankcase filters, and diesel oxidation catalysts (DOC). Schoolbusfleet.com conducted an interview with four companies about the emission control products they offer. Cleaire Advanced Emission Controls DPFs are verified by CARB to reduce emissions more than 85% (CARB, 2011). While DPFs reduce emissions more than the other technologies, they have more restrictive operating parameters and require maintenance on intervals periods. Some hybrid systems regenerate automatically, but can still be plugged in for cleaning (Roher, 2011). Given the wide range of operating parameters experienced by school buses, and the variety of idle and emission reduction technologies available, estimating the emission savings for a proposed project becomes necessary to determine project effectiveness.

1.2 Current Emissions Modeling for School Buses

There are no studies identified in the literature review that modeled school bus emissions using the distribution of operating modes. A few studies performed in-use and laboratory emission rate tests (J.S. Kinsey, 2007) (Hearne, 2003), (TTI, 2006), but no mobile-source emission models such as EPA's MOVES have been used to estimate the emissions of a school bus fleet using GPS vehicle activity data nor to evaluate the feasibility and effectiveness of a proposed policy change or implementations, such as automatic engine shut-off and idle reduction strategies. Some studies have used

MOBILE6 to estimate the emissions, but the rates are based on synthetic drive cycles and are generally reported in terms of an overall average gram per mile, based upon the characteristics of each roadway link. Performing laboratory emission testing under controlled conditions for a large sample of buses can be cost-prohibitive, so modeling using approved emission rate models is the general approach taken in policy analyses. Therefore this thesis will use monitored vehicle activity data coupled with emission rates from the approved MOVES model to estimate changes in emissions the vehicle fleet due to idle-reduction.

1.3 Research Approach and Objective

The purpose of the study is to instrument the CCSD fleet with GPS units and telematics, collect baseline idle data, and estimate reductions in fuel use and emissions expected to result from the idle control program. Given the wealth of vehicle activity data available to a portion of school bus operators, more can be done to understand the temporal and spatial characteristics of idling activity, since so little information about even the duration of idling exists.

The first objective of this research is to quantify school bus idling for the Cobb County School District (CCSD) bus fleet. Because no known analysis of local school bus idling existed, further detail on when, where, and how much buses idle is important to learn to focus the idle reduction strategies. Vehicle activity data are collected from in-use CCSD buses using GPS units and an idle detection circuit.

Another objective of this study is to develop operation-mode based emission rates that are applicable to an entire year and bus fleet, and then apply those emission rates to GPS in-use second-by-second vehicle operation traces to estimate total annual emissions.

After calculating the baseline emission estimates, the implementation of idle reduction strategies is then modeled to assess the emission and fuel savings possible for the project. Special focus will be paid to the idle emission rates, as the goal of the sponsoring project is to reduce the emission and fuel consumption caused by school bus idling. The MOVES project-level emission modeling process is used in developing applicable emission rates, as MOVES is the latest nationally-approved mobile source emission modeling software. Local data relating to the project area (e.g., fuel type, ambient temperature, etc.) are used to help ensure the applicability of the modeled emission rates. The emission rates from MOVES will be compared to emission rates developed in other studies for school buses and HDDVs and differences are discussed. Post-processing the vehicle activity data with operating-mode based emission rates is expected to significantly increase the accuracy of the emission estimates because there the modeling no longer relies upon the model's internal drive cycles, which are not representative of school bus operation.

1.4 Thesis Organization

The thesis is organized as follows: Chapter 2 covers the operational characteristics of school buses, as well as a project overview of the idle-reduction strategies being implemented for the Cobb County School District. Chapter 3 covers the equipment overview, development, construction, installation, and the testing of the idle-reduction and tracking telematics systems. Chapter 4 covers the idle event definition used in this study, and details the data collection, processing, and methodology of idling analysis. Chapter 4 and continues with the analytical results for idling and discusses the factors affecting idle duration. All vehicle activity data is verified and summarized in

Chapter 4 as well. Chapter 5 begins with a review of current emission modeling methodologies for school buses, and follows with an overview of the emissions modeling performed in this report. Detailed information about the inputs collected and used in the MOVES model is presented in Chapter 5. The last section of the chapter presents the emission rates developed from the MOVES model, as well as the estimated rates from EPA's Diesel Emission Quantifier, which is used in federal grant proposal comparative evaluation and project selection. Chapter 6 reports the estimated emission and fuel savings from idle control. The total emission control scenarios are developed and compared to assess the expected emission reductions associated with project execution. The final chapter provides a summary of the findings of the study and opportunities for further research as it relates to the discussed project and for the school bus emission modeling and idle analysis as it applies to jurisdictions and municipalities across the country.

CHAPTER 2

PROJECT OVERVIEW AND BACKGROUND

2.1 Operating Characteristics of School Buses

School bus drivers begin their shift with a pre-flight check of their buses. The engine is started and the driver inspects all lights and warning systems. Once the check is complete, the driver generally leaves the yard and proceeds to a bus staging area where the bus will wait until it is time to start picking up children on their first route of the day. School buses then serve their routes, picking up students along each route, and dropping the children off at school. Some buses will serve more than one morning route depending upon school start times. For example, an elementary school route may be followed by an intermediate school or high school route. Most buses return to their garage after the morning shift is complete. The afternoon operation includes traveling to the school and waiting for dismissal of students, loading the children, and then serving outbound routes (which often differ from inbound routes) to drop them off (again sometimes a second route for another school is also served). Upon completion of the afternoon shift, buses generally return to the maintenance yards.

School trips are characterized by a large amount of general idling because both private vehicles and school buses have to stop to load or unload children. Most extended idling occurs around the arrival and dismissal times on or near school grounds. For private vehicles, a longer and more variable idle time is experienced in the afternoon, leading to more congestion in the around school areas (Hallmark, Isebrands, & Liu, 2007). The Hallmark, et al. study goes into significant detail about the waiting time and idling of private vehicles, which now constitutes over 50% of all trips to school, but does not provide a similar analysis of school bus idling. School buses sometimes experience additional idling due to the presence of light-duty vehicle congestion near schools.

The average amount of idling performed by each bus per day, is still largely unknown and likely a function of local operating conditions and policies. This study will assess the amount of idling undertaken in the CCSD fleet and provide a framework of analysis that can be used in other jurisdictions. Simpler emission models such as DEQ, MOBILE6 and MOVES defaults can be updated with more accurate values after applying a similar analysis to school bus fleets across the nation.

2.1.1 School Bus Idling Operation Overview

Buses generally idle in the morning before stating their route to pick up students, as well as in the afternoon, waiting at the school for the dismissal of students. The reasons for idling vary, but as reported through a driver survey for transit buses, not all drivers understand the concerns related to bus idling. A recent study based on EPA's myths about idling asked Chicago Transit Authority bus operators whether four statements were true, false, or unknown. All of the statements were false. 69% of respondents believe (answered true) that a long idling period is required for engine warm-up, especially in cold weather. Additionally, 40% believe that it's better for an engine to idle than to run continuously, that idling is necessary to keep the cabin comfortable, and that it is better to leave the engine idling on a layover because shutting it off and restarting produces more pollution. Including respondents who did not know the correct answer, the percent that answered the last three questions incorrectly jumps to 53-60% (Ziring & Sriraj, 2010).

A confidential survey given to school bus drivers outlined a few key features that again call for better education of drivers and leaving room for improvement on the idle reduction front: 70% of bus drivers were interested in learning simple ways to improve air quality yin school zones, and 78% believed that most air pollution is from cars, truck, and bus exhaust (Hoelscher, 2010). Approximately 63% of surveyed drivers in Brazos County, Texas believed that air pollution is biggest environmental problem in the region. Unfortunately, the results from the questions quantifying idling were not provided (Hoelscher, 2010).

The knowledge of school bus operators is a function of the management and education relating to idling policies, but it can be assumed that additional education on the subject would benefit all parties involved. The American Transportation Research Institute compiled idling regulations from around the country. The limits on idling in most states is 5 minutes, but range from zero minutes in South Euclid, Ohio to 15 minutes in the City of Atlanta, Georgia, to 20 minutes in Vail, Colorado (ATRI, 2011). Fines are as high as $500 per offense in Atlanta and a range of $375 - $15,000 in New York for a first offense. New York City also includes a separate idling max of 1 minute, if the vehicle is adjacent to a public school (ATRI, 2011). Georgia Environmental Protection Division (EPD) has regulations for idling matching those of California's, and the Georgia Department of Education has guidelines on eliminating unnecessary idling (Georgia DOE, 2009).

The amount of pollution inside the bus has been the focus of a number of studies, summarized by Environmental Defense (2006). The factors that affect the phenomenon include wind speed and direction, open/closed windows, and the age and condition of the bus and engine. Two sources contribute to the self-pollution of the bus: the engine crankcase and the exhaust pipe. On most diesel engines, the crankcase is vented to the air, resulting in emissions of engine oil, unburned fuel and exhaust gases that leak through the piston rings. The exhaust pipe generally contributes 75-90% of the total particulate emissions from the bus. Ultrafine particles, less than one micrometre, black carbon and polycyclic aromatic hydrocarbons (PAH) such as naphthalene come from the exhaust pipe and the majority of $PM_{2.5}$ mass (less than 2.5 microns in aerodynamic diameter)comes from the crankcase (Environmental Defense, 2006). A study completed at Yale demonstrated the up to five times higher pollution levels inside a bus by equipping children's backpacks with monitors prior to, during, and after their trips to school, shown in Figure 2.1.

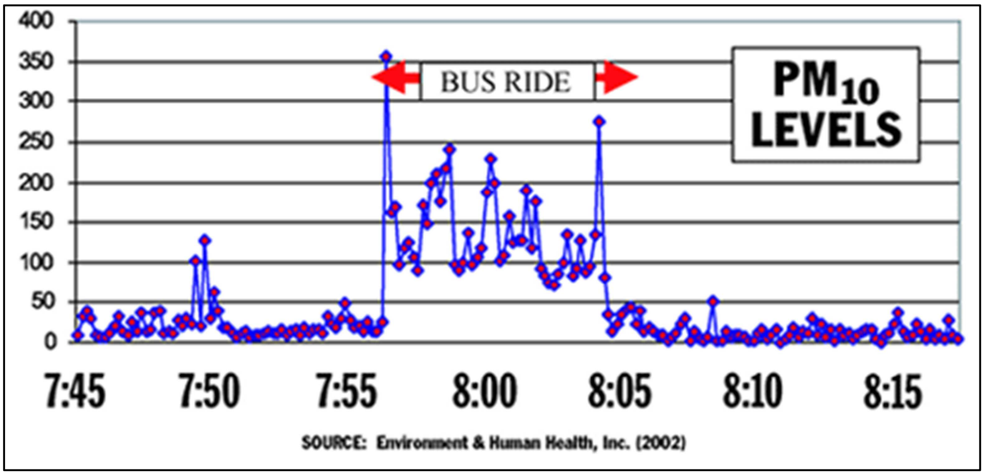

Figure 2.1: PM_{10} Levels from Child's Backpack during Bus Ride

Figure 2.1 illustrates the risk children face when riding in buses that have not been retrofitted with emission reduction technologies or controls. Unnecessary idling periods add to their exposure. The self-pollution effect of school buses has been relatively widely researched in comparison with school bus emission rate modeling. Other relevant health-impact studies include (J.S. Kinsey, 2007), (Fitz, Winer, & Colome, 2003), (Ireson, et al., 2011), (Ireson, et al., 2004) and (Marshall & Behrentz, 2005).

2.1.2 Current Idling Estimation for School Buses

The default amount of yearly idling used in the Diesel Emission Quantifier (DEQ) online tool is 270 idling hours per year, based upon the Clean School Bus USA Program. The DEQ is the USEPA online emissions quantification program used by grant applicants to quantify potential emission reductions from heavy-duty vehicle fleets associated with proposed emissions control strategies. Assuming 180 school days each year, the DEQ default is approximately 1.5 hours per bus per school day. Daily idle estimates for school buses reported in the literature are based on surveys or general expert estimates, rather than from detailed vehicle and engine operating records. Although not many studies have been conducted to determine an accurate idling amount, most jurisdictions and agencies recognize that idling is a problem.

One study on motor coach buses in historic district of Washington D.C. found that the median idle time per event was 11 minutes and the average was 16 minutes per bus. Idle amounts varied by temperature ranges as well as location. Each location averaged 15-22 minutes per idle event, but numerous cases of idling over one hour were observed (EPA, 2006). The operation of motor coaches is very different from school buses, so these estimates are not to be used when estimating school bus idle times; the idle estimates are provided as one of the very few idling studies on any type of bus. The policy in D.C. is 3 minutes maximum idling time, 5 minutes if the temperature is below 32°F, with an initial fine of $500, doubling after each violation (ATRI, 2011).

A program established in the Choctaw-Nicoma Park Public School system in Oklahoma used GPS tracking and mobile data transmission for testing the effectiveness of an idle reduction policy. Anderson and Glencross (2009) installed GPS devices on 14 of the fleet's 45 buses, which ranged in model year from 1999-2007. The Oklahoma study and other studies reported in the literature that are based upon GPS monitoring data base idling on key-on while the vehicle remains stationary. The percentage of time that bus drivers use only accessory power without running the engine is needed to refine these analyses. The total idling operating time for each bus was summed over the 10 months recorded (excluding summer) and divided by the 182 school days to get an average idle time per bus per day. Baseline data were collected in 2007 and 2008 data were collected after implementing the 5-minute idling policy. The post-implementation average idle time was estimated to be 23.7 minutes per bus per day, a reduction from a one- hour idle time per day baseline estimate. The baseline estimate of idling was based on driver and school employee interviews. One bus averaged just 0.72 minutes per day, judiciously following the no-idle rule, while the highest idler averaged 30.7 minutes per day. Based on the measured increase in fuel economy from 7.2 to 8.5 mpg, the idling policy saved nearly 5,000 gallons of diesel in 2008 for the 14 buses, an average of 355 gallons per bus. The study used EPA's DEQ to estimate emission reductions of 8.5 tons of CO_2, 0.0066 tons of PM, and 0.22 tons of NO_x (Anderson & Glencross, 2009).

2.1.3 Current Emissions Reduction Strategies for School Buses

In 2007, EPA tightened the certification standards for new heavy-duty diesel engines to 0.2 g/bhp-hr for NOx, 0.01 g/bhp-hr for PM, and 0.14 g/bhp-hr for non-methane hydrocarbons (EPA, 2011). A number of technologies have emerged to help meet these more stringent standards, to go along with ultra-low sulfur diesel (ULSD), which must meet a sulfur content limit of 15 ppm or less. Diesel PM mass is composed mostly of a carbon core, with metals, toxics, HC, and sulfates absorbed on the surface, shown in Figure 2.2.

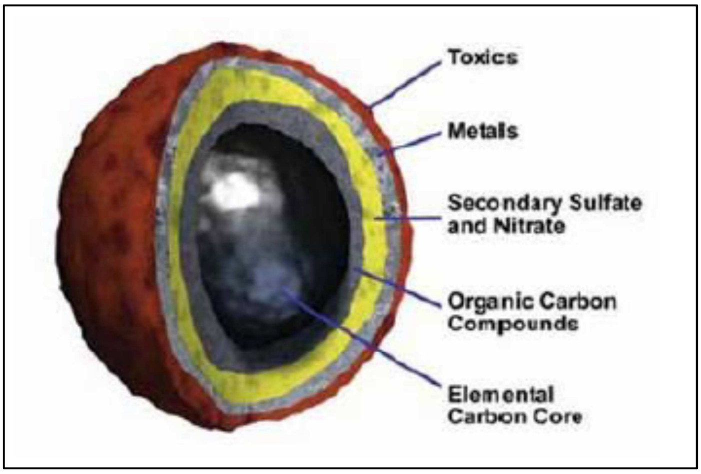

Figure 2.2: A Diesel Particulate (M.J. Bradley and Associates, Inc., 2006)

Some of the physical implementation options to reduce idling include direct fired heaters, auxiliary power units (APUs), and automatic engine shut-down. Direct fired heaters are small, lightweight diesel units that can be used for heating the cab of a truck or bus. Direct-fired heaters generally cost between $900 and $1,200 per unit. The goal is to reduce main engine idling by supplying a secondary diesel heater to provide heating in the truck cab. The estimated reductions for direct-fired heaters are reported as 6% fuel savings with 1,200 hours of idling per year (Indiana DEM). The benefits from direct fired heating systems are predominantly associated with extended idling or 'hoteling' of traditional long-haul trucking operations, and may not be applicable to school buses. Auxiliary power units (APUs) are small diesel powered generators (5 to 10 horsepower) mounted on the vehicle to provide air conditioning, heat, and electrical power to run appliances for an estimated cost of $6,000 - $8,000. (Indiana DEM). Automatic engine shut down/start up can be used to track vehicle activity and stop any unnecessary idling. An automatic engine shut down/start up system controls the engine start and stop based on a set time period or ambient temperature, and other parameters (e.g., battery charge). For trucks, these devices are available from some of the engine manufacturers with an estimated cost of $900 - $1,200 per unit. Any of these devices can be installed to reduce the idling and subsequent fuel consumption and emissions.

Closed crankcase ventilation (CCV) systems can be installed to reroute blow-by exhaust gases, which previously were vented to the atmosphere, back into the combustion chamber of the engine, thereby burning more of the harmful pollutants. Positive crankcase ventilation (PCV) was one of the earliest emission control strategies for LDVs, with national application beginning in 1962. Again, crankcase emissions can constitute up to 25% of total emissions, so installing these on older buses is critical to effectively managing diesel emissions (Cummins, 2011). Most buses manufactured after 2003 have CCV systems installed by the original manufacturer.

DOCs are a fairly maintenance-free retrofit device that works mainly to reduce PM by providing a catalytic surface that the exhaust gas passes through. The substrate has metals that oxidize HC and CO to CO_2 and H_2O. DOCs can reduce particulate emissions up to 40% using ULSD. DOCs also reduce CO emissions by 80% and HC by 80% (M.J. Bradley and Associates, Inc., 2006). The emission reduction estimates are supported by a number of studies by Brown and Rideout, Kittleson, Ayala, and Gautam (see Torrie Smith article) as well as CARB verification. The DOC lifespan typically ranges from 7-15 years or 100,000 to 150,000 miles. However, DOCs are not effective at reducing NO_x emissions. The CO_2 generated in the process is very small compared to the primary fuel combustion. DOCs generally cost $1,000 - $2,000 when purchased in bulk (Torrie Smith Associates, Inc., 2005)

High performance DOCs can achieve PM reductions up to 50%. The denser substrate, made of a unique blend of stainless steel coated with catalysts, is more efficient at oxidizing the particles while the engine is idling at low temperature than is a standard DOC. A temperature above 300°C must be maintained for the oxidation process to occur, and this temperature may not be provided during long idle operation (M.J. Bradley and Associates, Inc., 2006). Flow through filters aim to remedy this problem by increasing the thermal mass density, thereby retaining heat longer.

Diesel particulate filters (DPFs) physically capture diesel carbon particles and oxidize them to CO_2. The honeycomb ceramic substrate blocks off each cell so that exhaust must pass through a porous filter wall. Some DPFs include catalyzing metals for oxidization, similar to DOC, and some have active oxidation systems. Deposited particulates must be oxidized, or burned off and the DPF requires consistent high temperatures for regeneration, otherwise they may clog. Generally, the exhaust temperature must be above 260°F for 30% of operation for consistent reservation. Sulfur interferes with the processes used in DPF, so ULSD is required for their operation (Torrie Smith Associates, Inc., 2005). DPF can achieve reductions of 80% for PM, HC and CO (M.J. Bradley and Associates, Inc., 2006). DPFs used in combination with crankcase filtration nearly eliminate all measurable particle emissions, including ultrafines, black carbon, PAH, and $PM_{2.5}$ (Environmental Defense, 2006). Exhaust pipe insulation is available as a supplemental technology to keep exhaust temperatures high for proper oxidation in DOCs and DPFs.

Emission testing can be conducted using a variety of technologies. Remote sensing devices (RSD) can be used to collect snapshots of emission data as the vehicle passes the device on the roadway. The RSD monitors exhaust plume concentration ratios as the bus passes by a fixed location. The technology employs infrared and ultraviolet light beams across the emission plume and records the relative reduction in light by frequency. RSD technologies can also use a short wavelength light opacity to assess the fine PM concentrations. A more commonly used system is the portable emissions monitoring systems (PEMS). A PEMS device continuously records emission data at one-second intervals using onboard sensors. The added value is that buses can be studied while in-use rather than just in a laboratory or during dynamometer tests. PEMS testing also usually includes GPS tracking, and engine computer monitors to obtain real-time engine operating parameters. The g/bhp-hr emission rates are derived from instantaneous pollutant concentration, exhaust mass flow, and engine load or fuel use (M.J. Bradley and Associates, Inc., 2006). The SEMTECH-D PEMS model was used in the emission rate evaluation in New Jersey and in the TTI and Hearne studies examined in section 5.4.2.

2.2 Cobb County School District Project Details

Air pollution is a serious concern in the metropolitan Atlanta region. Stationary emission sources have been subjected to more stringent regulations and standards, but a significant portion (54%) of pollution is produced by the mobile-sources, including school buses (GRTA, 2001). On average, each person breathes over 3,000 gallons of air every day, and polluted air can trigger problems for the 30 million Americans that have been diagnosed with asthma (Georgia's Clean Air Force, 2011). Compliance with EPA established pollution levels has been a concern the region, leading to the formation of organizations such as The Clean Air Campaign in 1996.

Cobb County School District (CCSD) and Georgia Tech applied to EPA for an emission reduction project in 2009. The purpose of the study is to implement emission reduction strategies within the CCSD school bus fleet by adding diesel particulate filters and engine startup/shutoff idle control systems. The project was also designed to collect the data necessary to quantify changes in engine idling and fuel consumption, and to model the emission reductions of the project using standard EPA-approved modeling methods. Engine shut-off technologies are one of EPA’s verified diesel engine emission reduction strategies, but are not commonly used for school buses in the south.

Approximately 480 Cobb County School District buses are currently being outfitted with GPS tracking, idle detection circuits, and cellular communication systems for the purpose of this study. Baseline data on idling and vehicle operation are currently being collected, and will continue until the next phase of the project begins in the fall. A comprehensive tracking and driver warning system will be used to reduce idling of the buses, especially in designated no-idle zones. A future deliverable of the project is to install engine shut-off circuits and quantify additional emission reductions over the baseline scenario. The idle detection circuits are manufactured by Georgia Tech, and the engine shut-off components will be professionally manufactured. After configuring and testing all of the combination installation units (which consist of GPS unit, GPS/cell antenna, and idle detection circuit), they were delivered to CCSD for installation by their mechanics.

2.2.1 Funding

Funding for the project was derived from the 2009 federal stimulus American Recovery and Reinvestment Act (ARRA). ARRA included $300 million to support clean diesel activities through the Diesel Emission Reduction Act (DERA) program. $156 million was competitively awarded for emission reduction projects through the national program, and the Southeast Diesel Collaborative (SEDC) received about $18 million for these programs. After being ranked highly on the initial application in 2009, the project was passed-over for geographic diversity. However, funding was received in 2010 after another project did not proceed.

2.2.2 CCSD School and Fleet Information

Cobb County is large, suburban, county with a population of nearly 700,000 to the northwest of Atlanta and is counted in most metropolitan area classifications. CCSD is composed of 114 schools and serves nearly 97,000 bus-eligible students. The locations of the 114 schools are shown in Figure 2.3. The City of Marietta operates its own school district and fleet, but the city is in the geographical center of the county.

The District operates approximately 180 school days per year. However, the 114 schools operate on different schedules. Most elementary schools in CCSD start at 7:50 am and end at 2:20 pm. All middle schools in CCSD operate from 9:15 am to 4:15 pm. All high schools in CCSD operate from 8:25 am to 3:35 pm. The schedule is important when examining idle activity by location and time of day. Some buses serve more than one school. For example, a bus may transport elementary students and then transport high school students in the morning, given the offset starting times. Hence, analysis of idle time by bus can be a bit complex. Buses may have more or less opportunity to undergo extended idling depending upon their service schedule.

CCSD operates a fleet of approximately 1,150 buses, which is approximately 8% of Georgia's 15,263 school bus fleet. CCSD ranks as the 15th largest school bus fleet and 27th largest bus fleet in the United States. The fleet is composed of 869 conventional buses, and 281 special needs buses. CCSD employs approximately 950 bus drivers (not all buses are used on every day).

The District serves more than 21,000 bus stops on 887 routes per day and travels about 12.6 million miles per year. The fleet averages approximately 61 miles per bus per school day and consumes nearly 1.9 million gallons of low sulfur diesel fuel (maximum sulfur content of 15 ppm) per year. The average daily mileage includes all field trips and special events. On average, each bus consumes 9.1 gallons of diesel fuel per bus per school day, for an average fuel efficiency of about 6.7 mpg.

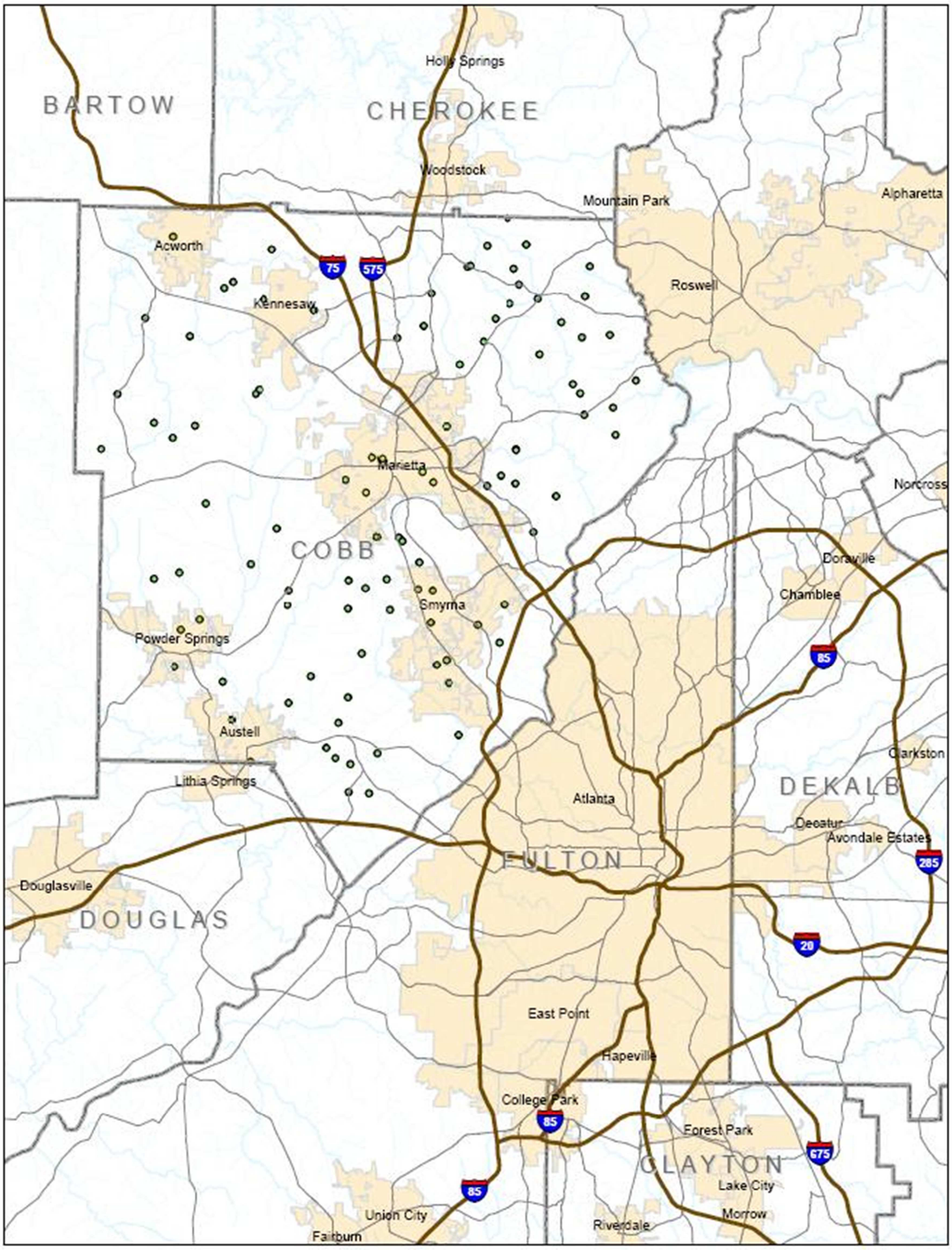

Figure 2.3: Locations of 114 Cobb County Schools

The School District maintains and operates its buses out of four different fleet maintenance yards, geographically spaced throughout the county to place buses closer to their primary service area. Each maintenance yard serves as a home base for inspection, fueling, maintenance, and storage of buses when school is out. The main fleet maintenance yard is located on South Cobb Drive in Marietta, near Dobbins Air Force Base and next to Southern Polytechnic State University. The other yards are located on Baker Road and Mars Hill Road in Acworth, and Sanders Road in Austell near Powder Springs. The locations are shown in Figure 2.4. Each yard manages more than 250 buses. Buses are parked in long rows (Figure 2.5) such that all buses and engine compartments are accessible.

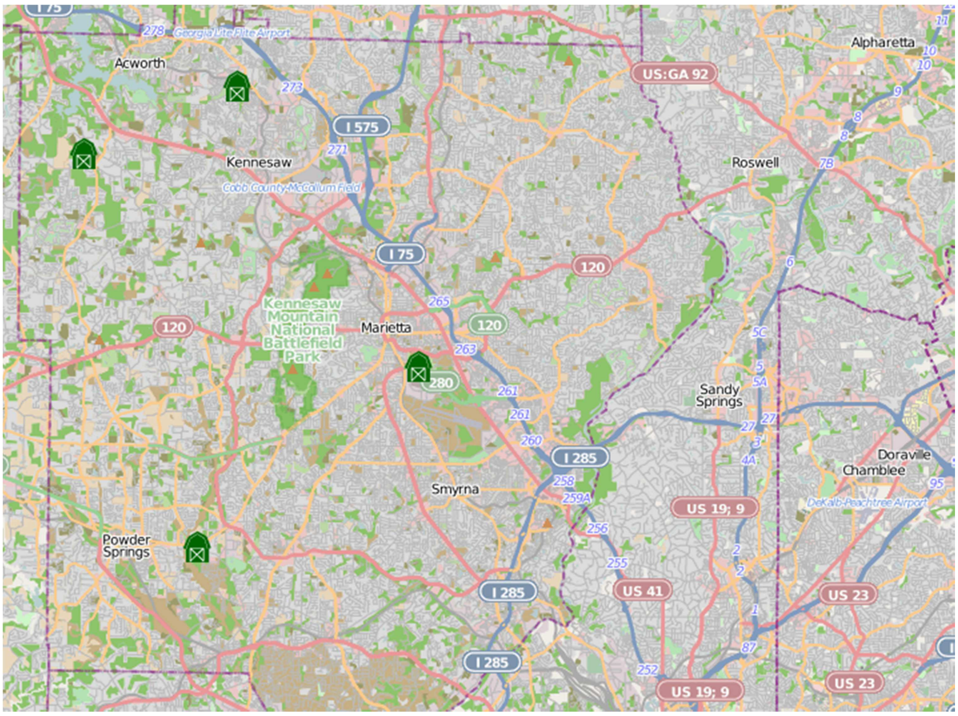

Figure 2.4: School Bus Mainteneance Yard Locations

Figure 2.5: South Cobb Bus Shop / Fleet Maintenance Yard

2.2.3 Cobb County School District Bus Fleet Instrumentation

The project includes the instrumentation of approximately 480 buses with onboard GPS/cellular systems. The 385 large buses in the project fleet range in model years 1998-2006, with about half of those buses being model year 1999 or 2003. One hundred and eight buses will be outfitted with diesel oxidation catalysts. The small buses in the study also range in model year from 1998-2006. CCSD purchased from a number of different manufacturers of buses, including American Transportation Corporation (AmTran), Integrated Coach Bus (IC Bus), Thomas Built, and Blue Bird Corporation. Table 2.1 and Table 2.2 show the breakdown of number of studied buses in terms of model years, body, and engine families.

Table 2.1: Large School Buses

Number	Year	Body	Engine Family	DOC
30	1998	AmTran	VNV444C8DARW	X
96	1999	AmTran	XNVXH0444ANA	X
50	2000	AmTran	YWVNX0444ACD	
18	2001	AmTran	1NVXH0444ACD	
26	2002	IC	1NVXH0444ACD	
85	2003	Thomas	3MBXH6.37DJC	X
28	2004	IC	3NVXHO444ACD	
52	2006	IC	6NVXH0365AEC	

Table 2.2: Small School Buses

Number	Year	Body	Engine Family	DOC
12	1998	Bluebird	VNV444C8DARW	X
3	1998	Thomas	VNV444C8DARW	X
12	1999	Bluebird	WNVXH0444FNA	X
3	1999	Thomas	WNVXH0444FNA	X
6	2000	Bluebird	YNVXH0444ACD	
6	2000	Thomas	YNVXH0444ACD	
6	2002	IC	1NVXH0444ACD	
35	2003	Thomas	3MBXH6.37DJC	X
6	2004	Thomas	3MBXH6.37DJC	
6	2006	IC	6NVXH0365AEC	

2.2.4 Cobb County Idling Policy

CCSD's idling policy can be found on their website (http://www.cobbk12.org/centraloffice/transportation/idlepolicy.aspx) and includes definitions for no idling zones. The no-idling zones include the morning delivery and the afternoon pickup in school loading and unloading areas, and field and athletic trip destinations. Drivers are instructed to shut off their engine as soon as stopping, and leave their radio on for communication. For afternoon pickups, drivers are not supposed to restart the bus until after all children are onboard and ready to depart. If the weather is cold, bus drivers are directed to congregate on one bus and idle to keep it warm, as far away from the school as possible. Given the health concerns associated with potential exhaust buildup in the idling bus, a better choice may be to have bus drivers move inside the school to a waiting area during cold weather. Drivers are told to inspect the bus in less than '8 to 10' minutes. Exceptions to the minimizing idling policy include for de-icing the windshield, or to thaw air brake lines. Idling is allowed for temperatures below 32°F to provide adequate heat, also for temperatures above 75°F (although none of the large buses are equipped with air conditioning). Lowering windows is recommended to reduce the need for idling in warm weather. After completion of this study, recommendations for modification will be made to CCSD to update their idling policy accordingly. Special sections will be included with respect to operation of the automatic engine shut-off elements.

2.2.5 Idle Reduction Strategy

The project procured through EPA and ARRA funding included the installation of diesel oxidation catalysts, which have since been replaced with closed crankcase filters. These units are procured and installed by CCSD, and are not the main focus of the Georgia Tech research team. Emission reduction estimates for these systems are provided as part of the project, but those estimates are not included in this thesis.

The CCSD idle emission reduction elements of the overall project include the installation of idle detection circuits and engine-shut off units in 480 buses. The base

GPS unit includes cellular communication elements to send second-by-second vehicle position and speed data to the Georgia Tech server, as well as data from external inputs such as the idle-detection circuit. Because engine shut-off circuits are not available off-the-shelf and must be professionally manufactured for the project, the project is divided into two phases. In the first phase, idle monitoring circuits manufactured by the Georgia Tech team are installed and an idle notification strategy is implemented. In the second phase, engine shutoff circuits will replace the idle-detection circuit and an automatic idle shutoff strategy is implemented.

In the first idle-control phase, maximum idle time thresholds will be established for specific anti-idle zones, such as school property and neighborhood parking areas, bus yards and bus staging areas, bus stops and pre-loading parking locations. When idle time exceeds the established threshold, the server web page displays the data for each bus that is idling. The CCSD dispatcher monitoring the web page will then call the driver over the radio to discuss the idle activity. Dispatchers inform driver that their bus has been idling for longer than a pre-defined time period (typically 5-minutes) and records call information into the online call log (including the stated reason for idling). The Georgia Tech server is capable of providing web page alerts, plus e-mail/messaging, and daily, weekly, monthly reports on school bus idling by bus or driver. Daily idle reports for each vehicle and summary reports for subfleets are generated for fleet managers. Toward the end of the first phase, drivers will receive training materials related to the idle-detection system and will be reminded about the importance of reducing idle activity as it relates to efficiency in terms of fuel consumption and health for themselves and their students. At the end of the first phase, the team will have sufficient idle data and call log information to quantify the impact of the idle warning system on idle activity.

In the second phase, the idle warning system will be combined with the automatic engine shut-off feature when idling exceeds a second pre-established threshold (typically 1-0 minutes) within an established anti-idle zone. Dispatcher warnings and call logs will continue as before, and the server will monitor the number of automated shut-off events that result. At the end of the second phase of the project, the team will have sufficient data to assess the marginal benefits of adding the automated shut-off system to the warning system (i.e. the benefits associated with shutting off engines remotely when the driver cannot be reached by the dispatcher).

In combination with the idle reduction strategies, additional emission reductions will be realized through the tailpipe emissions controls. CCSD is installing diesel oxidation catalysts (DOC) and crankcase filters to reduce emissions from on-road fleet activity. The vehicle activity data can also be used for engine load mitigation, to reduce the amount of time bus drivers operate their buses in the high-emission operating modes. Georgia Tech is monitoring hard acceleration and high speed activity so that driver feedback systems can be designed to reduce emissions from high engine load events. Add-on tailpipe and crankcase controls, coupled with engine monitoring and control of engine idle activity will reduce pollutant concentrations where children's exposure is highest.

2.2.6 Project Benefits

The most obvious and easily quantifiable direct benefit of the project will be the savings in diesel fuel. Simply put, eliminating unnecessary idling will reduce fleet fuel consumption significantly, saving CCSD thousands of dollars per year. Estimations of the actual gallon and dollar amounts of savings are discussed in Section 6.2. Vehicle maintenance costs are also expected to decline due to reduced engine wear. CCSD annual savings in fuel and other costs may be enough to pay for ongoing operation and maintenance of the anti-idle system (with equipment refreshed every 4-6 years).

The emission savings of the project are also a direct benefit of idle reduction and engine load mitigation strategies. Reducing the pollution from school buses will help the Atlanta metropolitan area meet national ambient air quality standards.

Additional secondary project benefits include the health benefits from emission reduction. These benefits are discussed in more detail in Section 0, and a conservative dollar estimate is placed on their value. The stored activity information and tracking systems can be used for route scheduling and optimization to increase the efficiency of the bus system, eliminating unnecessary miles traveled, reducing labor time, and further reducing fuel consumption. Reduced crashes are also expected because previous studies have demonstrated that drivers tend to experience fewer crashes when they are being tracked on a second-by-second basis (RMT GPS Tracking, 2008). Driver performance evaluation and information feedback is tied to that objective and will be used in an effort to minimize hard acceleration and high-engine load events. With the web tracking system, competitions could be established both inter and intra-school, to vie for the lowest daily/weekly/monthly idling by an individual driver or an individual school for a certain incentive or reward.

CHAPTER 3

IDLE SYSTEM MONITORING AND SHUTOFF

3.1 Equipment Development and Overview

Each onboard system consists of a GPS, a data transmission and receiving antenna, and an idle detection and engine shutoff circuit. Georgia Tech researchers designed the idle-detection circuit as well as the patent-pending idle-shutoff circuit. The detection circuits were constructed in-house by Georgia Tech staff. . The prototype engine shutoff circuits passed the field tests and being manufactured by a local electronics company to Georgia Tech specifications

The GPS units employed in the project were manufactured by RSN Consulting and are typically used in trucking fleet management applications including theft detection, recovery and tracking. The RSN1000 units (shown in Figure 3.1) were chosen for their compact size, familiarity, reliability: each unit can store up to 2,400 records when the device is out of coverage, with the data being automatically transferred to the server once communication is restored. The units also include three on/off input lines (for alarm inputs) and two output lines (to remotely trigger external devices). The standard device configuration is set to record key-on activity rather than engine-on activity. Hence, it is not possible to determine whether the engine is idling or if the operator only has the key in the on position to use accessories with the engine off. Georgia Tech researchers deployed an idle detection circuit and developed software algorithms to detect idle events.

Figure 3.1: RSN1000 GPS Unit

SIM (Subscriber Identity Module) cards were ordered from AT&T for transmission of the information from the units installed in the buses to the server at Georgia Tech. Each GPS system received a SIM card and was assigned a unique unit number from 421001 to 421500. The data antenna (Figure 3.2) is a dual-mode GPS receiver and a GSM/GPRS modem, placed (generally) of the roofs or rear taillight shroud of each bus. GSM stands for Global System for Mobile Communications and is used as one of the communication technology standards on AT&T's cellular communication network. GPRS stands for General Packet Radio Service and is the mobile data service for data transmission with speeds between 2G and 3G. The green-banded wire screws into the GPS input on the GPS unit and the black wire screws into the cellular communication port.

Figure 3.2: GPS Antenna and GSM/GPRS Modem

3.1.1 Detection Circuit

The idle detection circuit was designed by Georgia Tech. The patent-pending device has four inputs: the constant 12V bus power, the switched 12V bus ignition, the oil pressure sensor, and a grounded wire connected to a terminal on the bus. The oil pressure sensor activates when the engine is started and oil pressure increases above ambient pressure. A combination of relays and resistors sends a high/low pressure signal out to one of the inputs on the GPS unit, via a standard, Molex connector. Quick-connect wires were provided for all the connections between the circuit and the bus so that idle-detection units could be replaced with the shutoff circuits at a later date. Although the device is called the idle-detection unit, the unit really transmits the signal from the oil pressure sensor. The signal is forwarded to the GPS unit which transmits an on/off status for that input to the Georgia Tech server, where the input states are actually decoded to determine the idling status.

The power and ignition wires are connected to the idle-detection circuit with quick connect wires on one end, while the other ends were spliced onto the proper wires in the bus electrical box. One-amp fuses were located in between the bus and circuit for easy replacement. The oil pressure sensor was also connected to the circuit via quick-connect wires, and to the bus via a t-connector on the buses oil pressure gauge, which was also in the electrical box. The ground wire used a quick connect to the circuit and a ¼ inch ring connector to the terminal location in the bus.

3.1.2 Shutoff Circuit

Like the idle detection circuit, the new engine shutoff circuit also detects idling but is also capable of interrupting the ignition signal for three seconds to stop power to the engine. A bypass switch is included to ensure that maintenance staff can continue to idle the engine uninterrupted, even if a remote shutoff is triggered. The mechanic can use the bypass switch to ensure that the engine will not automatically shut off.

The shut-off circuit was installed on a bus that was already equipped with an idle-detection circuit and tested on June 22nd, 2011. The idle detection circuit was removed using the quick-connect ends and the idle shutoff circuit was put in its place. The GPS unit in the tested bus was assigned to its own unique port number on the server for testing The unit performed as expected, shutting off the engine after a testing idle value of 120 seconds. The bypass switch was also tested on an idling bus, and performed as expected: when activated, the idling bus did not shut off after 120 seconds. Three rounds of circuit re-design were undertaken to further improve system performance and the final prototypes were approved and 500 units were ordered in August.

3.2 Phase I Unit Construction

The majority of the Phase I idle detection circuit construction work was completed in December 2010 and January 2011 by a team of undergraduate students. The completion of a unit consisted of: manufacturing the circuit, testing the circuit, installing a SIM card in the GPS unit, numbering and labeling the GPS unit, flashing each GPS unit with firmware, configuring the settings on the GPS unit, testing the GPS unit for functionality and server connectivity, and packaging the unit and additional materials in shipping boxes. Figure 3.3 shows some of the manufacturing process.

Figure 3.3: GPS Units and Wiring Components Under Construction

Each SIM card was installed into the GPS units after recording the IMEI (International Mobile Equipment Identity) and phone numbers in an Excel document. This information was later entered into the server MySQL database to link transmissions from a certain SIM card to a unit number, and through the installation sheet, to an individual bus. The numbers were recorded carefully to avoid transcription errors that could cause undetected buses because of a miscoded IMEI number. The units were numbered sequentially in this process from 421001 to 421500. Each GPS unit was labeled with the unit number and phone number is both alpha-numeric and barcode formats. The unit number was written on three sides for ease of visibility in a number of different installation configurations.

To construct the idle detection circuits, relays and resistors were soldered onto the printed circuit boards (PCBs) before securing them inside the plastic project boxes with screws and metal lids. The circuit-side wiring connections, one leading to the bus, and one leading to the GPS unit, were constructed separately before being soldered together at the connection points on the PCB. To bring the connections of the wires into the PCB project box, holes were drilled into the plastic housing. The wires were tied in a knot to avoid pulling the soldered ends off of the PCB. The connections links required soldering, stripping, crimping, twisting, and tying wires. Heatshrink and electrical tape were used to surround the exposed components. Each circuit was tested with a multi-meter for the proper voltage and resistances across certain components. A completed circuit is shown in Figure 3.4 below. The wires on the left are the power (red), ignition (white), oil pressure sensor (green), and ground (black) connecting to the bus as mentioned before. The wire on the right has 1 amp and 3 amp fuses and connects to the GPS unit via the white Molex connector at the end.

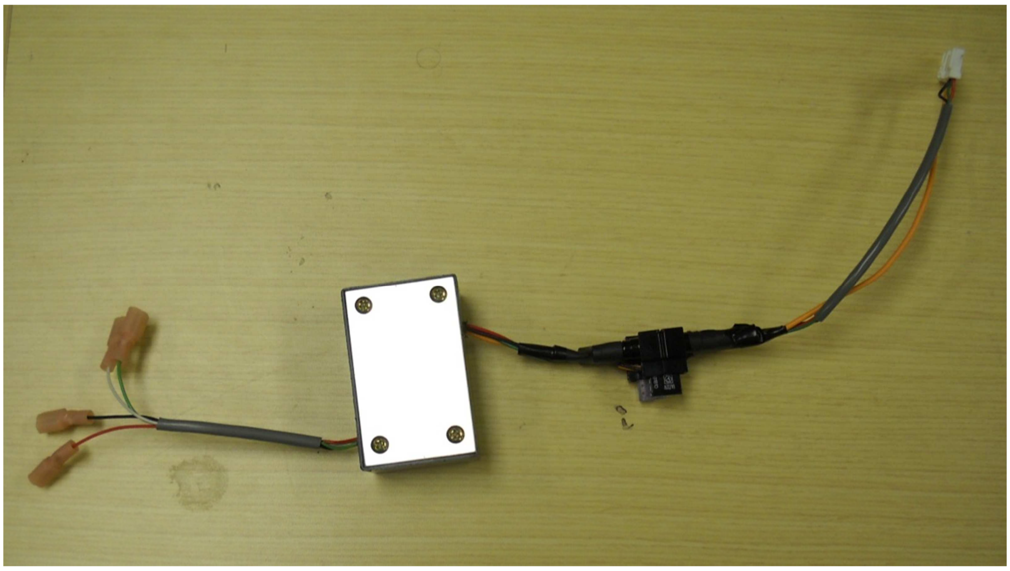

Figure 3.4: Idle-Detection Circuit Exterior

Heavy-duty Velcro tape was used to secure the idle detection circuit to the GPS unit, while still allowing the team to easily remove the circuit for replacement when the shut-off units arrive for Phase II of the project. Each system package included: one GPS unit, one idle-detection circuit, one piece of double-sided Velcro, one alcohol wipe for cleaning surfaces prior to antenna installation, two bus-side one amp fuses to protect the bus and idle-detection circuit, one oil pressure sensor adaptor, the quick-connect wires with ring connectors for the bus, one GPS modem and GSM/GPRS antenna, and one installation sheet. Figure 3.5 below shows a typical completed unit package, ready for delivery to CCSD bus yards.

Figure 3.5: Packaged Unit Ready for Delivery

Each GPS unit required the firmware to be flashed onto the hardware motherboard. Firmware flashing was completed using a proprietary software program. The GPS unit was connected to a flashing device that pulled power from a portable car battery (Figure 3.6). Also shown in Figure 3.6 is a testing box, which is identical to a flashing box with the exception of the end connections. The testing box has the four separate end wires for connection to an idle-detection circuit; the flashing box has a Molex connector for direct connection to the GPS unit. The GPS units were connected to the computer via a USB to serial communication wire and the proper driver software installed.

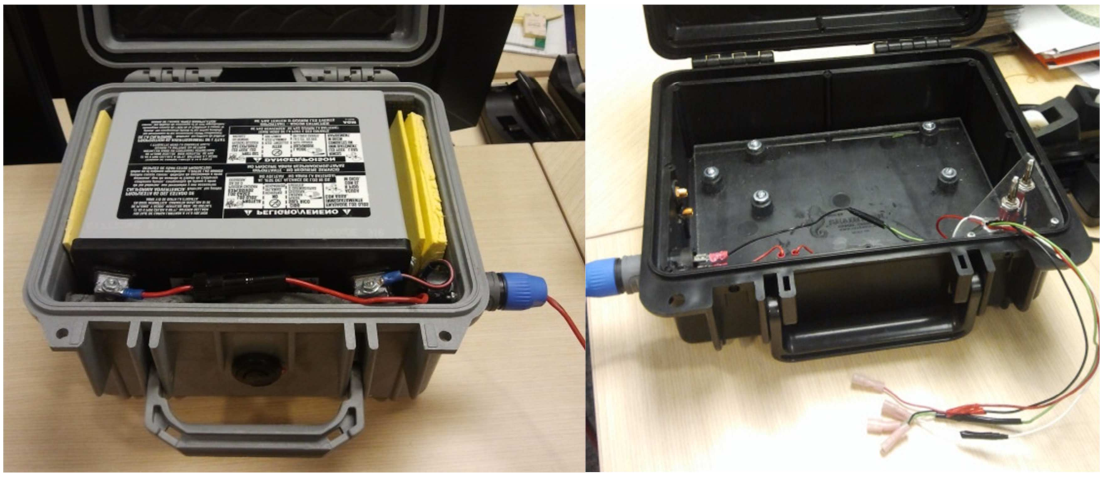

Figure 3.6: Battery (left) and Testing Box (right)

The testing box includes power and ignition switches to simulate the status of the bus. The oil pressure sensor is grounded to simulate a low signal when connected and a high signal when disconnected. A proprietary software package is used to configure each unit and verify proper communication between the server and GPS unit before field deployment.

3.3 Phase I Unit Installation

Installation of the units in the CCSD buses was handled by the mechanics of the CCSD Fleet Maintenance Department at the four bus maintenance yards, spread over Cobb County. The units were generally mounted inside the buses' electrical box in the back of the bus. Installation required splicing the units' wires to constant and ignition power sources. An oil pressure t-fitting was connected to the existing takeoff for the bus's oil pressure sensor and a second oil pressure sensor specifically selected for use with the idle monitoring circuit was installed at the connection. The antenna was mounted to the roof using heavy-duty adhesive tape and Gorilla Tape affixed the antenna wiring to the side of the bus. The ground wire was connected to a proper terminal in the bus. The installation sheets were completed so that a link between the CCSD bus number and the GPS unit number could be established later in the database. The install sheets contained additional information about the installation, such as the date installed, location of installed monitoring unit and antenna, and the name of the mechanic completing the work.

Georgia Tech delivered 200 units by December 17th, 2010 to the main fleet maintenance yard on S Cobb Drive, and 240 more units were delivered on February 21st, 2011, for the majority (440) of the 480 required units. Because the mechanics had to conduct required state vehicle inspections, only 69 of the 200 delivered units had been installed by February 21st. he delivery of 240 additional units constituted a substantial queue that CCSD staff would need to work through. Figure 3.7 shows the delivery and installation progress over the initial course of the project. Installation of the units ramped up during periods of bus inactivity.

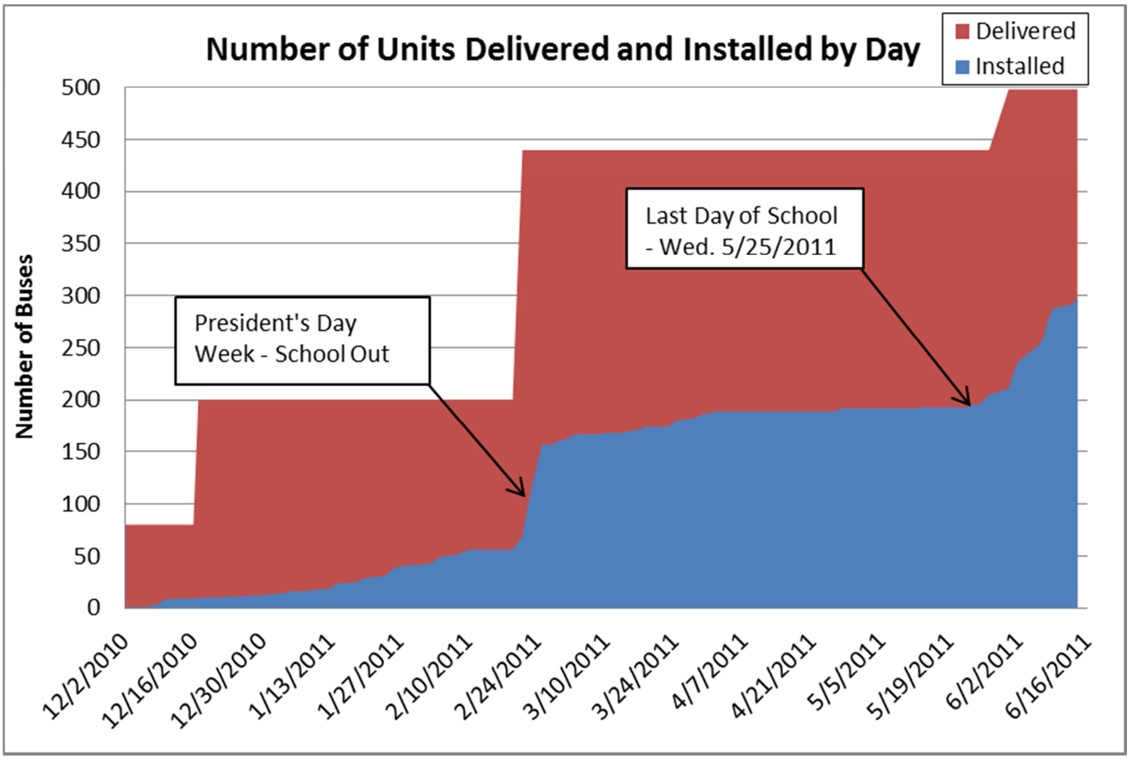

Figure 3.7: Number of Units Delivered and Installed by Day

Children received a week off of school during the days following Presidents Day, February 21st through 25th. During this week, nearly all buses were parked at one of the four bus maintenance yards due to the lack of school routes being run. A significant number of installations were performed during this week. Installations were being performed at some of the maintenance yards, one mechanic at each. CCSD reported that each mechanic could install about 8-10 units per day. The overall average installation rate for all mechanics and maintenance yards was 20.2 units per weekday. The summer installation rate ran a bit slower than the week in February, at 12.8 units per weekday. At this time, installations are still ongoing.

3.4 Server Data Flow

The data transmitted by all of the installed units are stored on Georgia Tech's server, where numerous software features have been implemented to trace the vehicles. The oil pressure sensor input status of each bus effectively determines whether a bus is currently idling. After the length of idling reaches a certain duration, the vehicle ID is added to a separate idle status table in the database. The idle table can be polled via the PHP-based CCSD project web page to pull a list of buses that are currently idling. The server also archives the second-by-second speed and position data for each trip, allowing users to query the a travel history for each bus, review the map and data for any individual trip, quantify engine idle activity, and check the installation status and connection status of all units and buses. The key information is reported to the server by cellular connection in real-time.

3.4.1 Unit Installation, Maintenance, and Status Monitoring Website

The Georgia Tech project website also includes password protected web pages for data management. The project support website allows researchers to enter installation data obtained from the install sheets that are completed by CCSD mechanics. The install sheets link unit numbers to CCSD bus numbers for use in the website tracking and display system, allowing CCSD and GT staff to track specific vehicles and identify units that are not reporting.

The project maintenance website also has the functionality to record installation removal information, in the case that a unit is broken in field and needs to be removed and brought back to Georgia Tech for further diagnostics and/or replacement. A current list of all buses installed is also provided on the maintenance site. The list of buses installed was frequently a deliverable back to CCSD to track the installation progress, and was used in weighting and adjusting multiple values used in this study. The date of installation of each bus is critical when calculating daily idle averages for the individual buses and overall for the instrumented fleet.

The most important portion of the maintenance website is the status monitoring page. The page monitors the last time a unit in a bus connected to the server, as well as the last valid GPS position reading, and an oil pressure sensor reading, using the information obtained from the GPS unit inputs, which have timestamps on each input on/off record. This information is used in the unit repair process described in section 3.5.

Green color coding is used for units that have connected to the server in all three regards the day prior to observing the monitoring page. Yellow connection status was applied to units that had not connected, reported a valid GPS position, or had an oil pressure sensor reading in one day. Any combination of the three checks that were two days or longer was coded red. On Monday mornings during the school year, most units were coded red, since buses had not operated on Saturday or Sunday. Teal-coded units were ones that were marked as installed in a bus, but had never connected to the server. Violet-coded units were not yet marked as installed (generally because an install sheet was either not completed or not received), but nevertheless had connected to the server. Gray-coded units were those that had not been installed nor connected to the server. Table 3.1 below shows the criteria used to develop an easy-to-track color coding system on the maintenance website. The possible issues listed in the third column of Table 3.1 were used as a preliminary step in identifying and fixing the issues associated with unit reporting. The monitoring webpage was updated each night at 2 am, so connection status changes could be seen one day after any changes occurred.

Table 3.1: Unit Monitoring Color Scheme

Color	Criteria	Possible Issues
Green	Connection, GPS, and OPS within last day	None
Yellow	Connection, GPS, or OPS not reporting in 1+ days	no operation in last two days (weekends)
Red	Connection, GPS, or OPS not reporting in more than 2 days	Bad unit, broken cell antenna, OPS not functional on bus, longer period of inoperation (summer or spring break)
Teal	Marked as installed, never connected to server	Wrong bus or box number on installation sheet, bad unit, broken cell antenna
Violet	Marked as not installed, connected to server	Unit installed but install sheet not yet received from CCSD, lab testing of units
Gray	Marked as not installed, never connected to server	Incomplete units in lab, or units not yet installed

3.4.2 CCSD Monitoring Website Tracking Features and Outputs

The website developed has a number of features to assist CCSD in managing the idling and operation of their bus fleet. Although the website is still under development, a number of key features are currently functional and are being used by CCSD bus dispatchers. The page shown in Figure 3.8 is the bus idling summary page. The page shows the CCSD bus number, installed unit number, school or non-school location, and idling duration of that bus, as well as links to the map application, and the ability to call the driver. A yellow idling status is for buses idling between five and ten minutes, and a red status is for buses idling more than ten minutes. This page helps CCSD dispatchers identify buses that are currently idling and gives the user options as what actions to take.

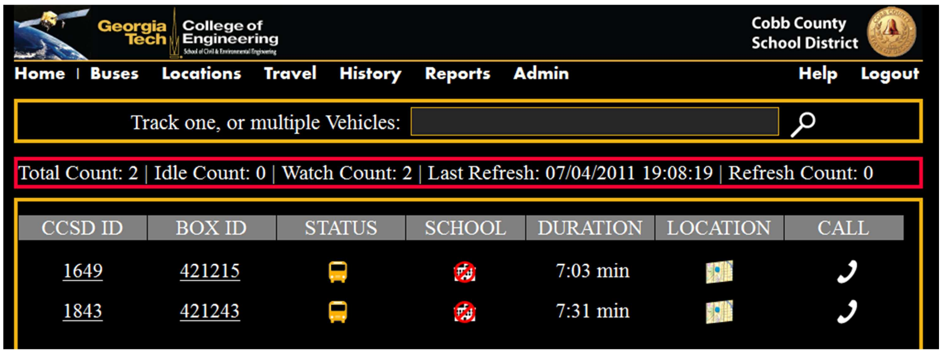

Figure 3.8: CCSD Monitoring Webpage Bus Idling Summary Page

The homepage (not shown), contains a list of all of the buses that are currently reporting to the server (i.e. the key is on providing power to the unit and a cellular connection has been established). The home page provides links to display the last known location of the bus or the real-time activity trace of the bus on a map. The current speed of the buses is also shown on the page, for easy detection of high-speeds that may be creating unnecessarily high engine loads or safety issues. The idle reports page (Figure 3.9) provides links to reports that summarize the amount of fleet-wide idling, by day or by month, the amount of idling by bus, and the list of 'top 20' lowest-idling buses for the day. This way, CCSD can actively manage and compare idling amounts over different time periods to determine if any additional policies or procedures developed have an impact on the amount of idling occurring in their fleet. The reports provided can be tailored to provide the information desired or required by the fleet supervisors, given the flexibility of the website and backbone of second-by-second school bus activity data.

Figure 3.9: CCSD Monitoring Webpage Idle Reports Page

Figure 3.10 shows the idle call log page of the CCSD webpage that can be completed by a dispatcher when reaching the bus driver by radio. On this page, dispatchers can log information about why certain buses were idling at certain times after calling the bus drivers. This allows for additional information to be appended to the idle events in the database, including the reasons for each idling event. After a significant period of system operation, a statistical assessment of idling events can be conducted and compared to the results of bus driver surveys found in the literature.

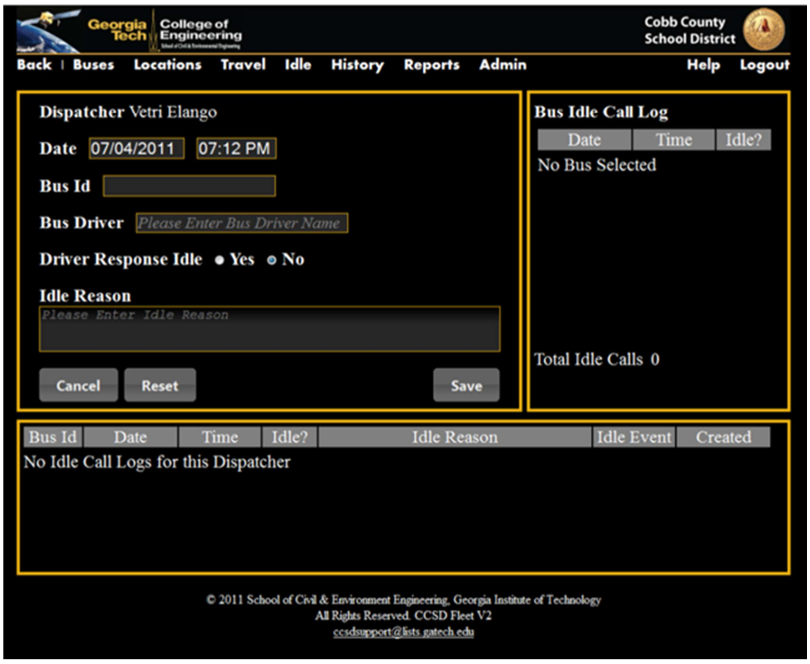

Figure 3.10: CCSD Monitoring Webpage Idle Call Log Page

A preliminary test of the idle warning call system was conducted on May 18th and 19th, 2011. The notes of one of the CCSD bus dispatchers indicated that a number of idle events were detected and the reasons for idling reported by the bus driver. The results of the call log are shown in Table 3.2. The fleet dispatcher did not record the idle time for all events; these records are marked with NA for not available. One instance indicates the need for additional driver education: bus 1399 reported dropping off students and that the buses were not ‘idle.’ Some drivers may not understand that *engine* idling can occur even when bus driver operations and actions are being performed. A number of calls resulted in the drivers reporting that the engine was off, so each unit was checked for any reporting issues, of which none were found. After verifying that the units are reporting correctly, since the possibility exists that the drivers incorrectly reported the engine state, the amount of idling before and after a certain number of notification calls could be examined.

Table 3.2: Idle Call Log Summary

Bus	Date	Idling Duration (mm:ss)	Reason
1416	5/18/2011	NA	idling, driver not on-board
1594	5/18/2011	31:25	idling
1815	5/18/2011	26:46	Baker bus shop, maintenance
1359	5/18/2011	17:04	Bus Idling, Driver Not On Bus
1390	5/19/2011	NA	engine off
1320	5/19/2011	13:29	engine off
1579	5/19/2011	10:13	engine off, key on
1399	5/19/2011	NA	dropping off students, 'not idle'
1531	5/19/2011	9:01	engine off, key on
1478	5/19/2011	11:23	engine off, key on
1368	5/19/2011	6:22	bus in motion
1737	5/19/2011	11:56	engine off, key on, fueling

3.4.3 Idle Reports, Driver Performance, Vehicle Trips, and Travel History

The website features also include automatic daily, weekly, or monthly reports on idling, which can sent via email to the fleet maintenance managers and directors. The notification and idle-warning system can be modified to email, text, or call each bus driver, and to provide data for use in evaluating the effectiveness of the different idle notification process. Individual summaries of idling activity can be sent to drivers on a per-bus basis via email, so that drivers can keep track of their personal idling amounts. If desired, drivers could receive information about their personal performance, as well as comparisons to other anonymous drivers across schools or fleet-wide.

In this effort, vehicle trips are defined by starting with a key-on event and ending with a key-off event. Hence, some 'trips' include when a bus was turned on and the engine was never started. These "key-on trips" are not true on-road trips, but it is was easier to classify and include these zero mileage trips for tacking purposes and in developing the reporting structure for the system. Most trips had the engine started (ignition-on), and either idled in place or moved for a full trip. If the key-on event was not logged due to lack of connectivity, the system detected vehicle activity and started the trip as soon as the first data point came in. Long time breaks in position change with the key or engine on were separated into two trips.

After the server scripts break all activity into various trips, this information can be retrieved from the archive information. Past information about any vehicle trip on any day is therefore accessible to CCSD through the web interface system, to help with case studies on past idling and other operational characteristics, such as average speeds over road segments.

3.5 Debugging, Testing, and Repair of Installed Units

The reporting status for server connections, GPS reporting and oil pressure sensor readings were monitored over the course of the project to detect any new problems with the installed units. This monitoring was performed through the QA/QC site, which has been discussed previously. Over the course of the project, the number of units with problems varied as some units developed new problems while others were fixed. Using spot-check QA/QC files, the initial number of units with problems was about 25% of the total number installed at that point in time. The QA/QC website is automatically updated every night, so archived data are not easily accessible from the site and would need to be re-created from the underlying database. However Table 3.3 shows a visual example of one of the QA/QC files, using the color coding described in Table 3.1.

Table 3.3: Example Status Monitoring File

Box Id	Vehicle Id	Last Connection Date	Last Valid GPS	Last Oil Pressure Sensor	Days Since Connect	Days Since Valid GPS	Days Since OPS	5/28/11 Field Notes	Bus Yard
421009	1305	5/22/2011	5/22/2011	5/21/2011	2	2	3	lab reflash and configure	SC
421415	1306	5/24/2011	5/24/2011	5/23/2011	0	0	1		SC
421203	1310	5/24/2011	5/24/2011	5/24/2011	0	0	0		SC
421100	1312	3/30/2011	3/29/2011	3/29/2011	55	56	56	reset - connected	SC
421105	1315	5/24/2011	5/24/2011	5/24/2011	0	0	0		SC
421150	1326	--	--	--					SC
421052	1327	5/24/2011	5/24/2011	5/24/2011	0	0	0	install fuse	SC
421396	1328	5/24/2011	5/24/2011	5/24/2011	0	0	0		SC
421205		5/24/2011	5/24/2011	5/24/2011	0	0	0		SC
421171	1331	5/24/2011	5/24/2011	5/24/2011	0	0	0		SC
421486	1338	5/24/2011	5/12/2011	5/12/2011	0	12	12	reset - connected	SC
421222	1340	5/24/2011	5/24/2011	5/24/2011	0	0	0		SC
421142	1365	5/24/2011	5/24/2011	5/24/2011	0	0	0		SC

Table 3.3, taken from the last day of school on 5/25/2011, shows a number of units with a range of problems. Units 421009, 421100, and 421486 show different values corresponding to the last time the unit connected to the server. Unit number 421009 had not connected to the server in two days, had no valid GPS reading in the last two days, and no oil pressure sensor reading in the last three days. Unit number 421150 was reported as installed in bus number 1326, but has never connected to the server. Unit number 421205 has connected to the server, but is not marked as installed in any bus. This is most likely due to the lag time between the actual installation and the reception of the installation sheet and that install being entered in the database on GT's end. The QA/QC file was used in field visits to the four bus yards to identify units for inspection and repair.

The field visits were generally conducted by a small group of Georgia Tech personnel equipped with a multitude of electrical tools, replacement parts and components, laptops with the diagnostic AWS Server, and cleaning tools and supplies. The personnel also brought water, bug spray, suntan lotion, hand wipes, and shop towels for comfort, cleanliness, and safety when performing work in the field. Connectivity to the server was tested for inspected units, as well as checking for things like oil residue on the connections inside the electrical box, a properly functioning bus oil pressure sensor, antenna placement, tight fit on all connections, power properly served to the units, and any ignition sensor or power problems.

The field visits required coordination with the fleet managers at each visited yard, to determine the location of each bus. With over 1000 buses to look through, finding the 40 or so buses that had malfunctioning units among the sea of yellow turned out to be one of the more difficult challenges. Most units were readily repaired through simple solutions like replacing fuses, or cleaning quick connect wires. Units that were unable to be fixed in the field were removed and taken back to the laboratory on GT’s campus for further diagnostics or replacement. The following figures are pictures from the field visits. Figure 3.11 shows a bus at the S Cobb Bus yard fueling station; Figure 3.12 shows the typical configuration of buses parked in back to back rows, making it somewhat difficult to search through the buses given the large number of buses present and lack of assigned parking slots.

Figure 3.11: Bus in ULSD Fueling Station at Maintenance Yard

Figure 3.12: Buses Parked in Maintenance Yard

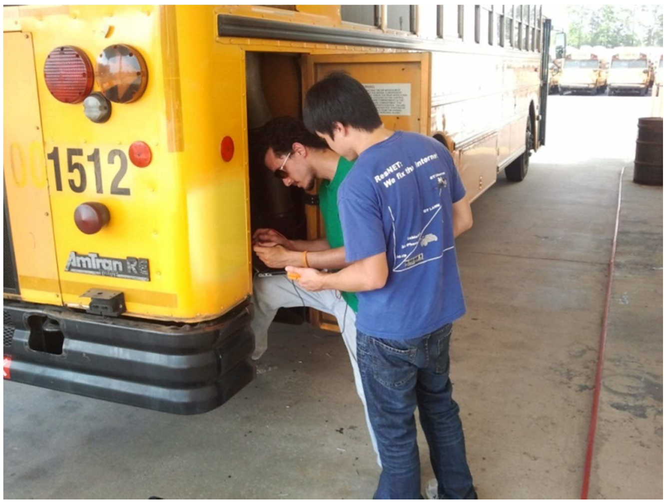

Figure 3.13: Research Assistants Testing a Unit in Field

Figure 3.14: Example of a Broken Cellular Antenna

Figure 3.13 shows undergraduates research assistants testing and repairing a unit in the electrical box of the bus, which were located in the right passenger corner of the bus for most models. Figure 3.14 shows an example of a problem that caused lack of connectivity to the Georgia Tech server; a broken cellular modem / GPS antenna, presumably by a low-hanging branch or other obstruction. The broken unit was replaced.

CHAPTER 4

BASELINE SCHOOL BUS IDLING ACTIVITY

4.1 Extended Idle Event Definition

The initial length of time that was considered a period of extended idling was 120 seconds. The definition of an idle event did not include location ranges due to GPS 'wander' at very low or zero speeds. The only classification factor used was a vehicle speed of less than 4 mph for a consecutive period of 120 seconds. This length was determined to exclude what could be considered idling at bus stops. When a bus stops to pick children at a designated bus stop, it is not reasonable or efficient for the driver to turn off the bus engine for the time it takes for the student to board the bus and find their seat. The 120-second extended idle threshold was based on discussions with CCSD as to what is a reasonable cut-off time as it relates to bus stops. A significant and easily quantifiable factor affecting the length of a bus stop is the number of students at each bus stop. These data (number of students per bus stop) is included in the bus route information from CCSD. On average, 5.0 students are picked up per stop by CCSD buses, and the average number of stops per bus route is 12.4. Bus drivers wait for students to sit in their seats before motoring away from the bus stop, slightly extending the length of time spent as bus stops. Another factor leading to extended idling at bus stops is parent/bus driver interaction, which from a customer-service standpoint, is not generally discouraged. The idle event definition used in the study is also supported by a typical intersection cycle length of 120 seconds. A bus could spend a large portion of that time waiting in a queue at an intersection.

The 120-second definition for school bus extended idle activity may pose certain limitations in the analyses of the data in the thesis sections that follow. For instance, buses that have an idle duration of less than 120 seconds will be ignored in the analysis, and buses stopped at a school at unloading 40+ children in the AM will be included in the idle events. The results in Section 4.5.5 will provide some insight on how the idle event definition affected the study.

The total amount of idling consists of all idle events when the bus engine is on and the bus is stationary, including time spent at bus stops and in intersection queues. The full amount of idling is necessary to create a total emission inventory, but is not expected to have much significance when analyzing extended idle.

4.2 Extended Idle Analysis

The actual amount of extended idling occurring in the CCSD school bus fleet could differ significantly from the average of 24.7 minutes per day identified in the Oklahoma study. Idle amounts may differ as a function of regional differences, climate differences, driver behavior and training, school policies, and a number of other factors. The methodology described in the following sections sets out to assess the amount of idling undertaken by CCSD buses. To fully characterize the idling of school buses, as a basis one must know the amount of idling per bus per day that occurs. The number of buses, or percentage of the entire fleet, that idle at all, or for a certain length of time, also needs to be known to understand the idling characteristics of a given bus fleet. The location and time of the idling events is also important, because exposure to the pollutants emitted from diesel exhaust has higher sensitivity at certain times and locations, most notably school loading areas in the morning and afternoon when children are present. Estimating the length of idle events for each bus in the fleet can imply information about the distribution of driver characteristics in terms of idle amount and location.

Other secondary factors worth considering to estimate their effect on extended idling include weather, particularly temperature, as well as very long idle events, and the number of recorded idle events per day. The total amount of idling over a given study period (which can be extrapolated to an annual amount) is useful and helpful for the estimation of idling emissions via any emission modeling technique such as MOVES DEQ. Other special trends such as determining reasons for a severe lack or abundance of idling or certain days will also be examined.

4.2.1 Study Period

The study period for this analysis was defined as the 86 days from February 28th, 2011 until May 25th, 2011. Although data were collected as early as December, a critical mass of instrumented vehicles in the fleet was not achieved until mid-winter. February 28th was the last Monday starting a school week in February, and May 25th was the last day of school for CCSD children and bus operation. During this period, 22,783 total idle events and 125,029 trips were monitored.

The study period excludes weekends and the week of spring break, April 4th-8th, during which bus activity was very low. To remove the weekend and spring break idling events, an excel file was created from CCSD school calendar data with the dates in the range of the study period, and a dummy variable: “1” representing a regular school day in the desired time range, and a “0” representing anything else, including weekends and holidays. This Excel file was imported into SPSS and a keyed match file merge was performed by date to add the dummy variable as a column in the study period IdleEvents SPSS file. All records with a value of “0” for regular school day were selected and deleted. This deletion consisted of 252 records of the 33,783 total study period records, leaving 33,531 idle events for regular school days. Weekends and holidays accounted just 252, or 0.8% of all of the idle events in the study period. The 58 regular school days analyzed account for 99.2% of the idle events in the study period.

The number of regular school days during the study period is 58, and there were idle events reported on every day during this period. To remove the weekend and spring break idling events, an excel file was created from CCSD school calendar data with the dates in the range of the study period, and a dummy variable: “1” representing a regular school day in the desired time range, and a “0” representing anything else, including weekends and holidays. This Excel file was imported into SPSS and a keyed match file merge was done by date to add the dummy variable as a column in the study period IdleEvents SPSS file. All records with a value of “0” for regular school day were selected and deleted. This deletion consisted of 252 records of the 33,783 total study period records, leaving 33,531 idle events for regular school days. The 58 regular school days analyzed account for 95.3% of all idle events in the dataset, and 99.2% of the idle events in the study period. The method to determine the breakdown of idling duration, rather than number of events, will be explained shortly hereafter. Table 4.1 provides a summary of the number of days and idle events for each of the data ranges mentioned.

Table 4.1: Dataset Summary

	Dataset	Study Period	Regular School Days	Weekends and Holidays
Date Start	12/2/2010	2/28/2011	2/28/2011	3/5/2011
Date End	5/26/2010	5/26/2011	5/25/2011	5/26/2011
Total Days	175	87	58	29
School Days	103	58	58	0
Weekend Days	50	24	0	24
Holidays	22	5	0	5
IdleEvents	35,156	33,783	33,531	252

4.2.2 Extended Idle Event Data Processing

Using the Idle Event definition of a minimum of 120 seconds, a log of all idle events was created from the raw second-by-second vehicle traces in the server database. Buses that had a speed of 4 mph or less for a minimum of 120 seconds were classified as an idling event. The speed ranges were established to account for GPS inaccuracy. Each idle event was assigned a unique identification number (idleEventsId). Each event was saved in a comma-separated-value (.csv) file with the following information allocated to each unique idle event ID: idle event start date and time, idle duration, latitude and longitude of the location the bus idled, as well as the (bus) vehicle identification number and (GPS) unit identification number. An example of the data format is provided below in Table 4.2. The 'idleEventsType' column is blank and will be filled out in with the location categorization using the GIS processing summarized in a following section.

Table 4.2: IdleEvents.csv Data Format

idleEvents Id	vehicleId	boxId	idleEvents StartDate	idleEvents StartTime	idleEvents Duration	idleEvents Latitude	idleEvents Longitude	idleEvents Type	lastModified
1	4260000793	421003	12/3/2010	14:20:42	135	33.86024	-84.60603		27-4-2011 14:52:44
2	4260000793	421003	12/7/2010	14:56:43	359	33.86818	-84.63447		27-4-2011 14:52:44
3	4260000793	421003	12/8/2010	6:18:58	515	33.85909	-84.64315		27-4-2011 14:52:44
4	4260000793	421003	12/10/2010	16:34:13	137	33.97369	-84.71262		27-4-2011 14:52:44
5	4260000793	421003	12/13/2010	7:02:58	143	33.89190	-84.62296		27-4-2011 14:52:44

The IdleEvents.csv was retained in multiple formats, most notably Excel spreadsheets and IBM's Statistical Packages for Social Sciences (SPSS) data format.

4.2.3 Weather Data

Weather data for Marietta, GA were collected from wunderground.com weather history archive (Weather Underground, 2011). The data are reported from the Dobbins Air Force Base weather station. Daily weather information was collected for December 1st, 2010 until June 16th, 2011, which is before the beginning and past the end of the good three months of idle data in the study period. Weather for Marietta is assumed to approximate weather conditions for the entire county in this analysis. The weather variables available include daily high, low and averages for: temperature and dew point in degrees Fahrenheit, humidity in relative percent, pressure in inches mercury, visibility in miles, and wind in miles per hour. The other variables available were daily precipitation in inches, and a note to classify rain, snow, thunderstorms, fog, etc.

After collecting the information from the website and saving the data in an SPSS file, the variables high low and average temperature, high low and average humidity, high low and average wind speed, and note were merged with the IdleEvents files using a keyed match by date. The main weather variable hypothesized to have an effect on the amount of idling is temperature, as one of the main reasons for idling is cabin climate control heating or air conditioning (EPA, 2010).

4.2.4 Geographic Information System Processing

To identify the approximate location of each idle event, Geographic Information System (GIS) analysis was used. Each idle event was then classified by location category: events outside of Cobb County, idle in school zones, idle at bus stops, idle at intersections, idle on-street, and idle off-street. The goal of the spatial categorization was to compare the amount of idling at each location, in terms of average amount per bus per day, to get a good idea of the spatial distribution of idling activity that occurs within the bus fleet. Idling in school zones is likely to be of greater concern because due to the health consequences associated with children's pollutant exposure.

4.2.4.1 School Zone, Bus Stop, and Intersection Mapping

CCSD provided Georgia Tech with hand-drawn maps of the parking zones overlaid on satellite imagery for each of the 114 Cobb County schools. Georgia Tech researchers manually created polygons in ESRI's ArcGIS software package to represent these parking zones.

Bus route information was sent to Georgia Tech for processing and geo-coding. Geocoding is the process of creating or extracting a latitude and longitude coordinate from other geographic information, in this case, a street address or intersection. The bus routes contained approximate addresses for each of the 16,384 bus stops on the 1,319 bus routes in the file. CCSD has indicated that about 33% more bus stops exist (discussed in Section 2.2), but these additional data are not yet available. The bus stop addresses were matched to latitude and longitude coordinates using a MapQuest database script. Using the latitude and longitude coordinates, bus stop idle event locations can be plotted in the GIS files.

A limitation of the analysis performed is that not all of the bus stops are currently geo-coded, because of address matching failures. Just 53% of the bus stops provided could be matched from the CCSD provided list to the MapQuest database, for a total of 8684 geo-coded bus stops. Many of the addresses in the MapQuest database included prefixes or suffixes such as Example Rd NE and S Sample St. These prefixes and suffixes were not included in the bus stop information provided by CCSD. The matching produced multiple output address matches from 600 Example Rd, such as 600 Example Rd NE, 600 Example Rd NW, etc. Hand matching of these addresses to latitude and longitude was not reasonable due to the sheer number of mismatches and small scale of the data. Many of the streets in the dataset are in small neighborhoods and common data sources such as MapQuest may not include accurate geo-locations for addresses provided on these streets. The Georgia Tech team is working on a new Flash-based web user interface that will allow dispatchers to readily add the locations of the missing bus stops.

Roadway links were allocated into the GIS file from a shape file obtained from Cobb County's website. The roadway links were current as of July 2010 (Cobb County GIS Office). A tool downloaded from ESRI was used to create nodes for the intersections of the roadways. Given the current amount of road work and construction, it can reasonably be assumed that some roads were constructed between July 2010 and March 2011, and are not included in the file (Cobb County Department of Transportation, 2011).

4.2.4.2 Idle Zones and Geo-fencing for Spatial Categorization

The latitude and longitude for each idle event was extracted from the IdleEvents file, and compared to the location or proximity of each feature type. The location category or classification is shown in Table 4.3. Each idle event proceeded through a step-wise classification check, starting with the test to determine whether the event occurred outside Cobb County and ending with the test to determine whether the idle event occurred off of the transportation network. The prioritization resulted in a straightforward system within the GIS to ensure that each idle event fell into one and only one classification category. The distances criteria for each classification category were based on visual assessment of school zones, bus stops, intersections, and street configurations. Refinements were made to the initial distance numbers to help capture the events as accurately as possible.

Figure 4.1 shows a school with a small cluster of idle events (shown in the green or teal dots) located just outside of the initial 500 foot radius. Based upon case study analysis of a subset of schools, the school zone radial distance was changed to 600 feet for the final analysis.

Figure 4.1: Idle Event School Location Categorization Example

In the categorization process the latitude and longitude of the idle event is first compared to the borders of Cobb County. If the point is outside the county, it is categorized as an out of Cobb County idle event. If the coordinates are within Cobb County, the system moves to the next category and tests whether the coordinates are within the pre-established polygon of the school parking area, or within a 600 foot radius of the school center point. Occasionally the established parking area is outside of the 600 foot radius, so both tests must be run. If either criteria is met, the event is classified as a school zone idle event. The GIS tool then tests whether the idle event location is within 60 feet of the street centerline and within 300 feet (linearly) of the bus stop to classify the event as a bus stop idle event. Three hundred feet was employed because bus drivers do not stop at the exact location every day. Idle events matching these criteria are categorized as bus stop idle events. The next test is within 60 feet of the street centerline and within 500 feet (along the roadway link) of an intersection, to capture the potential length of a very long queue at a traffic signal. Idle events meeting these criteria are classified as intersection idling events. Figure 4.2 shows logged idle events as green dots around an intersection, as well as the eastbound queue and the 500 foot longitudinal classification criterion.

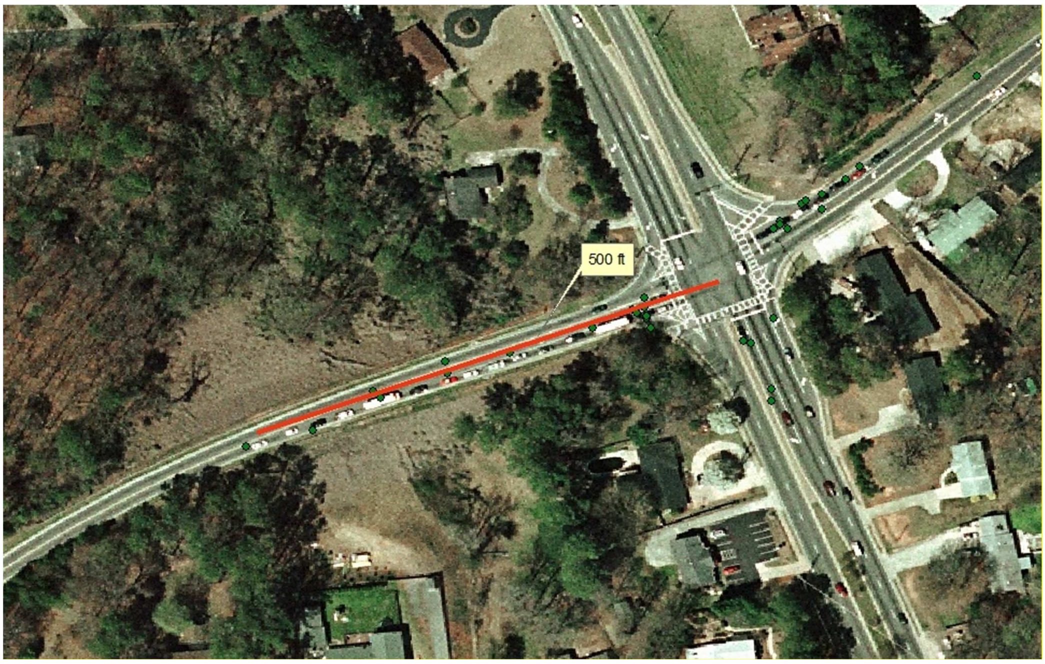

Figure 4.2: Idle Event Intersection Location Categorization Example

If none of the above location criteria were matched, the software then tests for 60 foot proximity to a street link. The events that fall within 60 feet of the centerline are classified as on street idling events. The remaining events that are farther than 60 feet from the street centerline are categorized as off-street idling events, typical of large parking lots.

The priority ranking prevents duplicate classifications. For a school at the corner of two roads and the parking lot adjacent to the street, it is very possible that an idle event location meets the criteria for the on street, intersection, and school zone categories. Given the close proximity of the school and the provided guidance in the definition of idle events at 120 seconds which accounts for a reasonable intersection waiting time, the event is most likely actually occurring in the school parking lot, where the majority of idling events occur. The idleEventsType column in the IdleEvents file was populated with the proper categories from the categorization process. The location categories, or idle event types, are used in the analysis with the duration of the idle events and dates; an example is shown in Table 4.3 below.

Table 4.3: IdleEvents.csv with Categorized Locations

idleEvents Id	vehicleId	boxId	idleEvents StartDate	idleEvents StartTime	idleEvents Duration	idleEvents Latitude	idleEvents Longitude	idleEvents Type	lastModified
1	4260000790	421003	12/3/2010	14:20:42	135	33.86024	-84.60603	2	27-4-2011 14:52:44
2	4260000790	421003	12/7/2010	14:56:43	359	33.86818	-84.63447	5	27-4-2011 14:52:44
3	4260000790	421003	12/8/2010	6:18:58	515	33.85909	-84.64315	1	27-4-2011 14:52:44
4	4260000790	421003	12/10/2010	16:34:13	137	33.97369	-84.71262	3	27-4-2011 14:52:44
5	4260000790	421003	12/13/2010	7:02:58	143	33.89190	-84.62296	5	27-4-2011 14:52:44

Note that with the rules that have been implemented, it is possible for events to be mis-classified. For example, given the classification test order, an intersection idling event would be categorized as school zone idle if the intersection was located within 600 feet of the school centroid. Some of the bus stops that were not geocoded and idle events may be categorized as on-street events. In the processing, the GIS software would see an idle event that was actually at a bus stop, but it wouldn't recognize it as a bus stop event since the stop was not geocoded, and move to the next priority level. When road segments are missing from the network database, some on-street idle events may also be classified as off-street events. Incorrect or missing geo-coding for school zones, bus stops, and intersections could lead to some idle events 'filtering down' and landing in a category with a lower priority level. However, the probability of missing a school zone classification is very low because the system was tested afterwards with the research group and the errors were corrected. The main problem in the classification system is primarily associated with missing bus stops. A similar effect could be possible for road links constructed and new intersections created between July 2010 and March 2011. However, the location categorization is considered a good approximation to the distribution of idle activity in the stated categories for the CCSD bus fleet, due to the large sample size of bus stops, intersections, roadway links, and school zones that have been provided.

4.2.5 Statistical Analysis

All of the data collected from the systems were imported into the IBM's SPSS statistical software package to analyze various relationships and characteristics of the idling. Before continuing to the process for evaluating these aspects of idling, the limitations of the idle event definition as specified in section 4.1 should be noted and considered when analyzing the results. Again, idle events shorter than 120 seconds in length are included in calculations of overall idle for the fleet (occurring both onroad and offroad) but short idle durations are not identified as part of extended idling in the database for subsequent analysis. Idle events shorter than two minutes are not really the main concern for idling, since shutting down the engine and restarting is only efficient after three minutes (EPA, 2011).

Similar processes and actions were performed on the three datasets: the full study period, regular school days only, and weekends and holidays only. Many of the analytics would require pruning of each database to a restricted set of cases to analyze. The main functions in SPSS used include visual binning, select cases using a case range, select cases using an IF function on different variables, Frequencies, Descriptives, Merge Files – Add Variables, Compare Means, and Aggregate functions.

One of the most important variables to be analyzed was the average amount of time idling per bus per regular school day during the study period. Data for weekends and holidays were also flagged and analyzed separately. The three base files containing all idle events corresponding to each dataset were aggregated by unit number and date. The summary variables included were average idle event duration, average number of idle events, and most importantly the sum of idle event duration. With this final statistic, the total duration of all idle events in one day for one bus is entered into a column is the post-aggregated data file. The descriptives feature was then used to obtain the average number of idle events logged per bus per day, the average duration per idle event, and the average total daily idle time per bus.

To assess the number of unique buses analyzed on any given day, only the study period data file was needed because it encompasses all days within both subsets of data – regular school days and weekends and holidays. The idle events were aggregated by unit number and date with the summary variable being the frequency or count of events logged by each bus on each day. This aggregation grouped all idle events from one bus and one date together. The file was then aggregated again by date, with the summary variable being the frequency of cases aggregated. The second aggregation grouped all of the buses idling on a given date together, and the number of buses was counted. This method did not average any values from the two distinct day types (regular school days and weekend/holidays), since the results were differentiated by each day. Similarly the time binned dataset mentioned before was aggregated a second time by 15 minute time bins to record the number of unique buses idling across various hours of the day.

To examine the distribution of idling events and duration over the course of day, SPSS's Visual Binning Function was used on the idleEventsStartTime variable. The visual binning helps users assign categorical groups to show the distribution of events across a variable. The options for visual binning include custom-defined cutpoints, equal-width cutpoints, quartile cutpoints, equal percentile cutpoints, and cutpoints within 1, 2, or 3 standard deviations of the data. For the analysis, 15 minute equal-width cutpoints were used. The visual binning tool uses the start point as the first value in the dataset, which happened to be 12:08:56 AM, shifting all of the groups to odd numbers like 7:23-7:38 AM. A new case with zero idle duration was inserted to the dataset at time 12:00:00 AM, to time align all cutpoints to equal 15 minute intervals. After each idle event was classified into a 15-minute time bin, the distribution of idle events and total idle event duration were plotted by aggregating the file by the time bins and using the sum of idle events, the sum of idle event durations, or the sum of average idle event duration.

Frequencies were taken for the number of idle events from the study period file to determine the percentage of idle events that occur in each location category. The average length of idling events in each category was calculated using the compare means function in SPSS with IdleEventsType as the independent variable and the idle event duration as the dependent variable. To determine a breakdown of average idle lengths at different locations, the study period dataset was aggregated by unit number, location category and date, with a sum of the idle event duration as the summary variable. The average total daily length of idling per bus can simply be calculated using the compare means function of SPSS, which takes the average of all bus-days in category 0, out of Cobb, and then category 1, school zone, etc. IdleEventsType was the independent variable and the summed duration of idle events as the dependent variable.

To make comparisons that may relate to driver behavior (assuming that drivers are generally assigned to a specific vehicle), the average daily idle time by each of the bus was compared for regular school days. The regular school days file was first split into AM and PM sections using the case selection feature by time. The files were then aggregated by unit number and date, with the summary variable being idle time duration sum. This aggregation collected all idle events for a bus on one day and summed the durations together separately for AM and PM idle events. The resulting file was aggregated again by unit number with the average idle duration as the summary variable. The final aggregation produced the desired variable of the average idle time by each bus in AM and PM periods. Some bus drivers that idle for more than 45 minutes per day can be considered heavy idlers. Since each unit number corresponds with one bus and each bus has one driver, the unit numbers also act as bus driver identifiers.

Weather information was appended into the base dataset files at the outset of the project, and comparisons were made between the weather (particularly temperatures) on each day to the number of buses idling, the total amount of idling per day, and the average daily idle per bus. Ordinary linear equations were developed to try to predict the amount of idle as a function of low, high, or average daily temperature. Excel's trendline feature was used for the development of these equations.

4.3 Fleet Instrumentation Results

In summarizing the amount of extended idling that occurred in the instrumented bus fleet, the first thing to consider is the number of buses actually reporting idling during the study period. The number of buses installed was tracked via the installation sheets returned to Georgia Tech. Temporal variation in the number of buses idling was examined within the context of the CCSD school year calendar. The data collected from installation sheets and entered into the server and the number of buses reporting idling on a given date were plotted on the same graph to yield the following results.

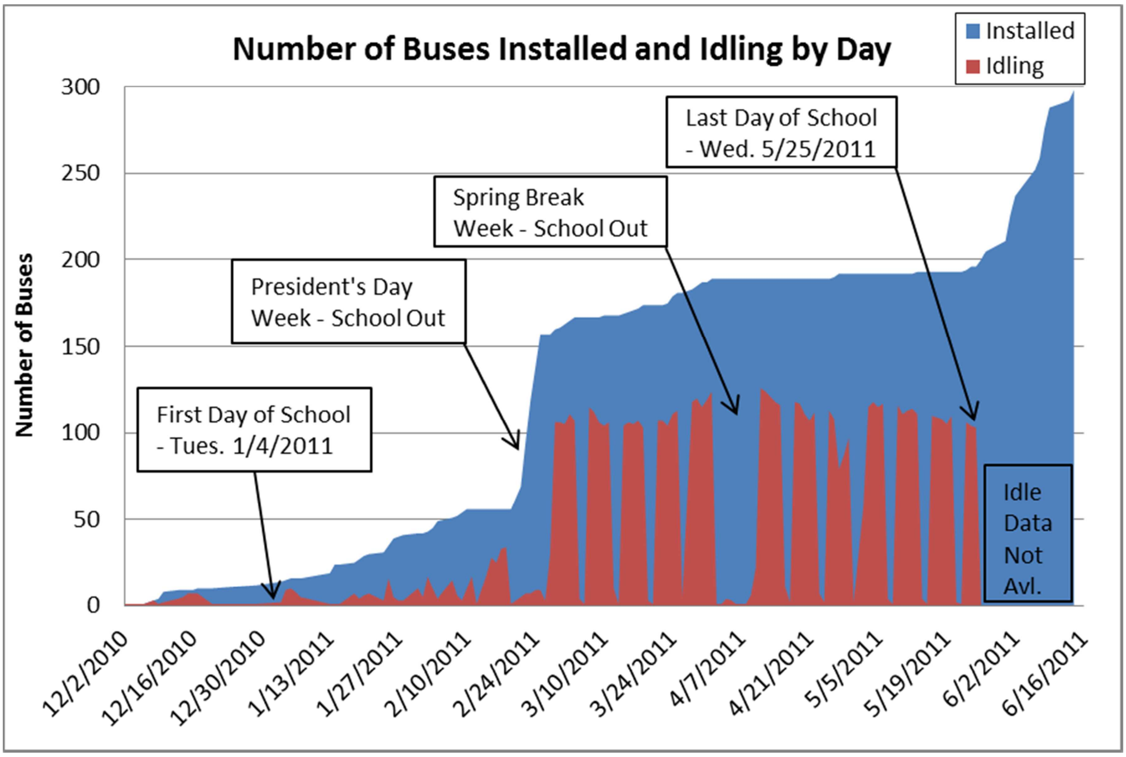

Figure 4.3: Number of Buses Installed and Idling by Day

The number of buses installed and idling varied significantly throughout the study period. Until the end of February 2011, very few buses had units installed. The lack of installations during this time period can be accounted for by the delivery of the majority of the units from Georgia Tech to CCSD at the end of December and the inability to perform numerous installations during school when the buses are in service. Students had one week off of school in February around President's Day, and the number of buses installed shot up during this period, as all buses were stored in the bus maintenance yards. The number of buses idling was very low this week due to drastically reduced vehicle operation when school is out.

The high installation rate was not observed during the week of spring break in April. CCSD reported that week was spent performing state inspections of the buses so very few installations were performed. The number of buses reported idling during the spring break week was also very low. All other weeks from the beginning of March until the end of the school semester on Wednesday May 25th, 2011, show a significant number of buses idling during the weekdays followed by low periods of activity on the weekend. The installation of units picked up significantly again after the end of the school semester. The idleEvents.csv file used for the analysis in this study contained events until May 26th, 2011, one day after the end of school.

The robust data range, as previously defined as the study period, is considered to be February 28th, 2011 through May 25th, 2011 excluding the week of April 4th - April 8th for spring break and school holidays. This is essentially nearly three months of data from March, April, and May. Using the values in this data range, on an average weekday, 109 of the 183 installed buses reported idling (about 60%).

However, this figure does not tell the whole story. Not all of the units installed were properly connected to the server and reporting at any given point of time. In fact, as mentioned before in section 3.5, approximately 25% of the installed units had some sort of initial issue with reporting data to the server. To adjust for the lack of reporting, the percentage of buses expected to actually be idling is the quotient of the reported number of buses idling and the percent of buses reporting.

$$\% \, Buses \, Idling = \frac{Reported \, \% \, Buses \, Idling}{(100 - \% \, Buses \, Not \, Reporting)} = \frac{60\%}{100\% - 25\%} = 80\%$$

Using this adjustment, we can determine that, on average, nearly 80% of the buses did have at least one idle event over 120 seconds in length per day. This adjustment also leads to the suggestion that of the buses installed, about 145 of them log at least one extended idle event per day. The estimate for the full project fleet is 384 of the 480 buses. Across the entire Cobb County fleet, the number of buses idling (for more than 120 seconds) on a given day is expected to be 920 of the 1150 total buses.

4.4 Vehicle Activity Data Verification and Results

The vehicle activity data files were first reviewed for potential outliers. Of the total 132,000 trips logged, over 15,000 (11%) had a total duration of zero as classified in operating bins. Zero duration files are created when a driver turns the key but does not start the engine, a 'key-on trip'. The total number of key-on trips for each bus was checked, and then compared to the total time the bus had a unit installed and was therefore able to report trips. Two buses, with unit numbers 421088 and 421076, accounted for 2,933 of the key-on trips. Each individually had at least 900 more key-on trips than the third highest unit. Upon checking the unit status of the top key-on trip loggers, the team determined that the ignition reporting system for those two boxes were broken. The ignition output of the boxes was constantly on, populating the trip table with an excessive number of trips. The data from these two units were removed from the dataset prior to analysis. Figure 4.4 shows the number of key-on trips on each day in the study period.

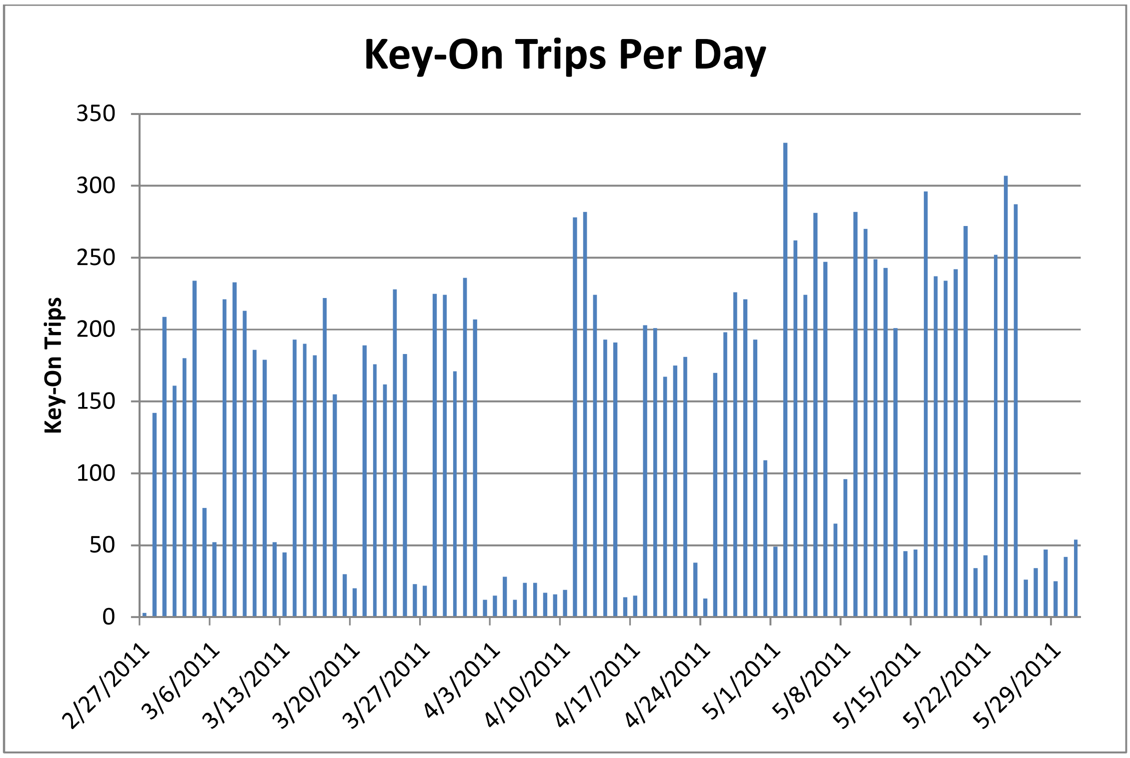

Figure 4.4: Key-On Trips per Day

The buses also logged key-on trips with a direct correlation to the school days when vehicle activity was high. The number of key-on trips reported was much higher on school days, which is in agreement with the idling amount results shown in section 4.5.2. To analyze the bus activity in terms of emissions, the key-on trips were not included in the emission calculations; since the bus engine is not on, no emissions occur during these trips. Further coordination with CCSD will be performed to determine if operational characteristics create these key-on only trips. One example would be keying on the bus to check certain electrical components or the mileage before starting the engine of the bus, as required by CCSD policies.

The total vehicle activity recorded in the dataset was 117,500 moving or idling trips (excluding key-on only trips), 20,758 hours of activity, and 297,595 total miles of activity. The VMT recorded was approximately 2.4% of CCSD's 2009 annual VMT of 12.6 million miles. The Over the 58-day study period (32% of the 180 total school days), while units were being installed, the average monitoring day included about 127 of CCSD's 1150 total buses (11%).

4.5 Extended Idle Activity Results

The number of buses idling was plotted against the high, average, and low temperatures for the three month period February 27th, 2011 through May 26th, 2011. Figure 4.5 shows the resulting plot. The graph does not show a strong correlation between the temperature and number of buses idling. A stronger correlation is expected for the total amount of idling activity per day, rather than just the number of buses idling. In fact, the number of buses idling remains relatively constant across the study period, regardless of temperature. The number of buses idling is not expected to be a function of weather conditions. The graph of total duration of idling and average idling per bus against temperature is shown in section 4.5.4.

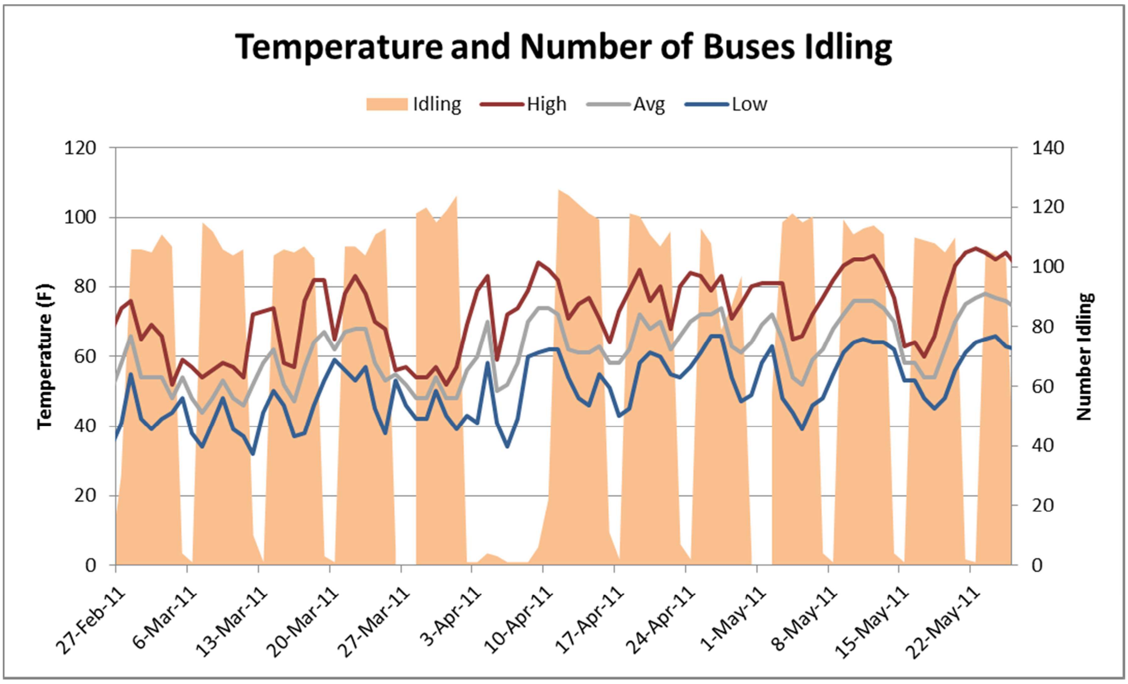

Figure 4.5: Temperature and Number of Buses Idling by Day

The lowest number of buses idling on a weekday occurred on Wednesday April 27th, just 79 buses of the 144 total connected and reporting to the server that day. The low on April 27th was 66°F, one of the highest low temperatures in the dataset, indicating that =the lower number of buses idling might be related to temperature. The number of buses idling was also plotted against humidity and wind, but these variables were even weaker with respect to correlation with the number of buses idling.

Table 4.4 provides a summary for the study period idle events. The total number of events in the AM was about 18% higher than the number of PM events, but the total duration of idling was 40% higher in the AM – 1,881 hours compared to 1,348 hours. This is supported by the fact that the average length of idle events in the morning is longer than the average length of an idle event in the PM, by about 18%. Each bus also averages 16% more idle events in the AM than in the PM, also contributing to the 40%

increase in total idle duration in the AM. The average number of idle events per bus per day is 5.24, and the average length of idling per bus per day for the entire study period is 30.1 minutes. The maximum length single event of idling in the study was 4.96 hours. The 95th percentile of idling for one bus on one day totaled 1.14 hours.

Table 4.4: Summary Idle Statistics for Study Period

	Study Period		
Idle Events	AM	PM	Overall
Total Number of Events	18,291	15,492	33,783
Averge Length of Idle Event (min)	6.2	5.2	5.7
Average Idle Events Per Bus Per Day	3.18	2.75	5.24
Idle Amount			
Total Amount of Idle (hr)	1,881	1,348	3,229
Average Idle Per Bus Per Day (min)	19.6	14.3	30.1
Times			
Average Idle Event Start Time	7:34 AM	3:02 PM	-
Maximums			
Maximum Single-Event Idle By One Bus (hrs)	-	-	4.96
99th Percentile Daily Idle By One Bus (hrs)	-	-	1.94

Table 4.5 summarizes the idling results for regular school days only. Eliminating the weekends and holiday events from the dataset leads to averages for all weekdays which school is in session for. The average extended idle per bus per day is slightly reduced from the study period dataset from 30.1 minutes to 29.7 minutes. Per bus, 37% more idling occurs in the AM than in the PM, 19.3 compared to 14.1 minutes per day. These numbers don't add up to the 29.7 total minutes per day because the averages are only for when the buses are idling in that given timeframe. A bus that idles in the AM but not the PM would contribute to the AM and daily average, but not the PM average. One bus recorded a 3.26 hour idle event on a regular school day. The average AM and

PM start times were 7:34 AM and 3:02 PM, which correspond well with the approximate times of operation for the CCSD schools, which was covered in section 2.2. The average amount of idling is likely affected by the season studied, and will vary more over the course of the year.

Table 4.5: Summary Idle Statistics for Regular School Days

	Regular School Days		
Idle Events	AM	PM	Overall
Total Number of Events	18,170	15,361	33,531
Averge Length of Idle Event (min)	6.0	5.1	5.6
Average Idle Events Per Bus Per Day	3.19	2.76	5.29
Idle Amount			
Total Amount of Idle (hr)	1,832	1,309	3,141
Average Idle Per Bus Per Day (min)	19.3	14.1	29.7
Times			
Average Idle Event Start Time	7:34 AM	3:02 PM	-
Maximums			
Maximum Single-Event Idle By One Bus (hrs)	-	-	3.26
99th Percentile Daily Idle By One Bus (hrs)	-	-	1.94

Table 4.6 summarizes the statistics for weekends and holidays. Since this dataset only includes 252 idle events over three months, the variation between each day is much wider than the more typical regular school days. The total amount of idling recorded throughout the study period on weekends and holidays was 88 hours, or 2.7% of the 3,229 total hours. When a bus did idle on a weekend, the average length of time it did per day was longer than on regular school days at 49.9 minutes. Also the average idle events logged on the weekend are much longer than the average regular school day idle length at 21 minutes, or more than three times the length of the average idle event on regular school days, 5.6 minutes. The weekend and holiday AM and PM breakdowns

carry little weight since they do not correspond to before and after school activity patterns. Further discussions with CCSD are needed to determine a list of general reasons why buses would be idling on the weekends. The maximum single idle event in the study period occurred on a weekend at 4.96 hours.

Table 4.6: Summary Idle Statistics for Weekends and Holidays

	Weekends and Holidays		
Idle Events	AM	PM	Overall
Total Number of Events	121	131	252
Average Length of Idle Event (min)	24.4	17.9	21.0
Average Idle Events Per Bus Per Day	1.83	1.90	2.38
Idle Amount			
Total Amount of Idle (hr)	49	39	88
Average Idle Per Bus Per Day (min)	44.6	34.0	49.9
Times			
Average Idle Event Start Time	8:51 AM	3:56 PM	-
Maximums			
Maximum Single-Event Idle By One Bus (hrs)	-	-	4.96
99th Percentile Daily Idle By One Bus (hrs)	-	-	-

4.5.1 Idle Summary By Bus-Days

The results of the SPSS visual binning of idle event length is shown in Figure 4.6. The bins of daily idle time are broken down into 5-minute groups for 0 to 60 minutes and an additional group for 60+ minutes. The frequency on the primary ordinate axis is the number of bus-days recorded in each of the total length bins. A bus-day is a case where one bus idles a certain length of time on one day. Grouping the first six bars, for buses that idle, 60% of all bus-days accumulated less than 30 minutes of idle time during that day. In contrast, 32% of bus-days accumulated between 30 and 60 minutes of idling, and 8% recorded more than 60 minutes of idle per day. At the extremes, 6% of the bus-days monitored exhibited only 5-10 minutes of idling per day, and 8% of the time, buses logged 60+ minutes of idling per day.

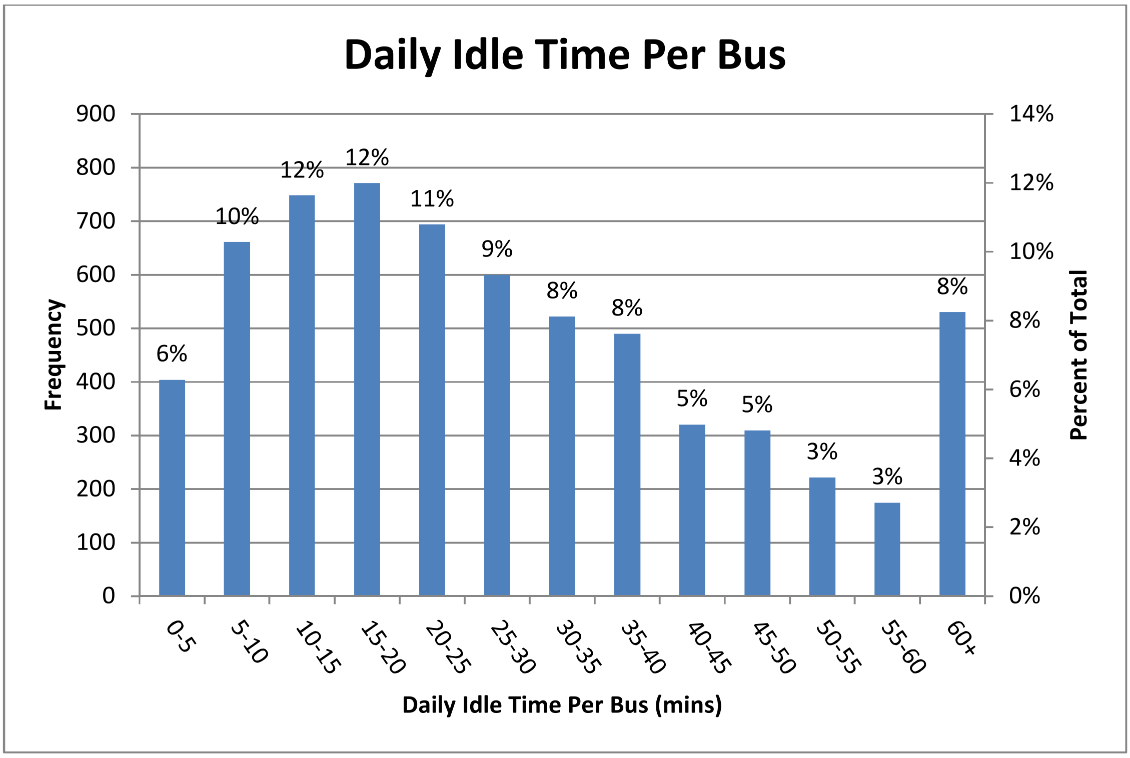

Figure 4.6: Daily Idle Time Per Bus in Study Period

4.5.2 Idle Summary by Bus

To further understand the idling distribution, the average daily idle time per bus is plotted for the monitored buses. The frequency on the ordinate axis of Figure 4.7 is the number of buses. Each bus in the dataset idled different lengths of time on different days, which was shown in Figure 4.6, but the average amount of time each bus spends idling is displayed here. If a bus idled 4 minutes one day, 30 minutes the next day, and 60 minutes the third day, the average daily idle time fort that bus would be 31 minutes and fall into the 30-35 minute bin. Of the 154 buses, 64% of buses average between 15 and 25 minutes per day. The last four bins, 45+ minutes per day, constitute the heavy idlers, of which there were 15 of the 154 total. Approximately 10% of the buses account for 19% of the total idling.

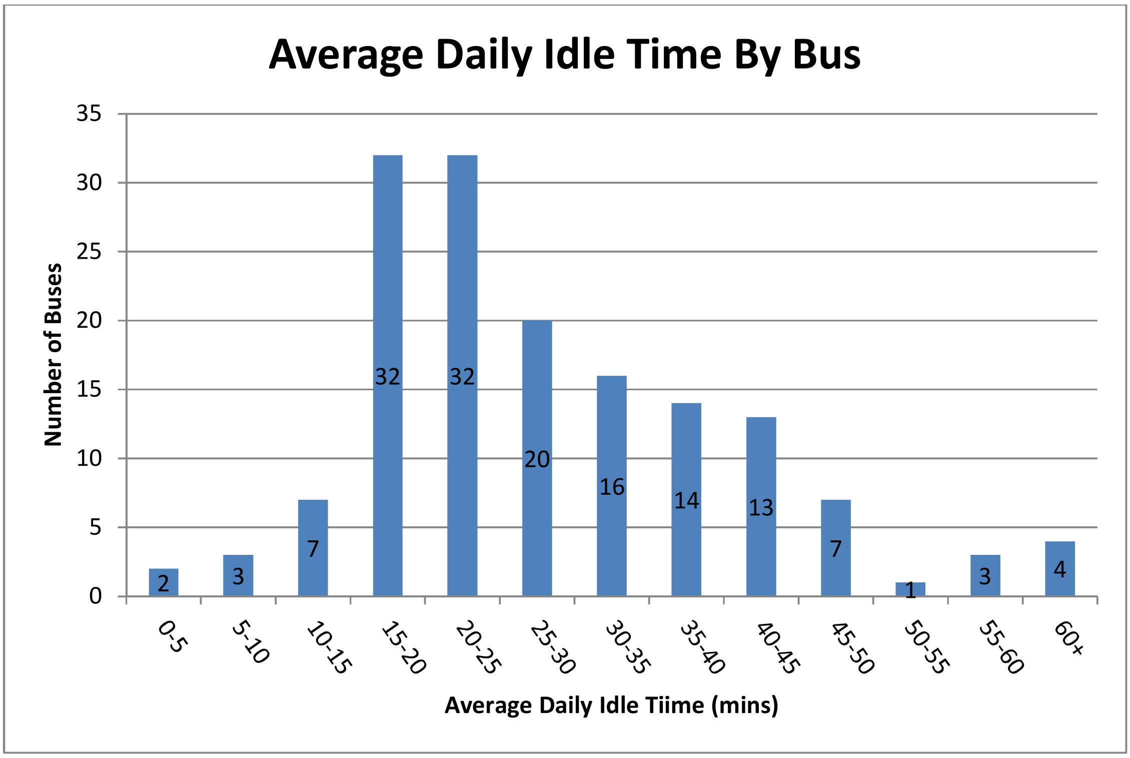

Figure 4.7: Average Daily Idle Time for Each Bus in Study Period

Looking at different buses/drivers, the average AM and average PM total idle per day is compared across all of the buses. The results are displayed in Figure 4.8. Each bar shows, for one bus, the total AM average idle per day, stacked on top of the total PM average idle per day. The bars are ranked by the sum of the AM and PM average, not the overall average per day. The AM idle time, shown at the bottom of each stack, is generally longer than the PM average idle time, matching the average AM/PM lengths presented earlier. Some buses never idled in the afternoon and their red bar reaches all the way to the top of their stack. Bus 1679, corresponding to unit number 421088, was the highest idler, averaging nearly 160 minutes per day. Bus 1647, corresponding to unit number 421076, averaged nearly 120 minutes per day. Excluding buses that did not idle at all (20% of the buses), the lowest idling bus was bus 1479, corresponding to unit number 421035 all the way at the right of the chart. The four lowest idlers reported no PM idling, and an average AM amount of 17 minutes or less per day. This graph shows that there are some heavy idlers, but the total idling is controlled mostly by the middle population that idle between 20 and 45 minutes per day. An expanded version of this chart is available in the appendix to show each unit number.

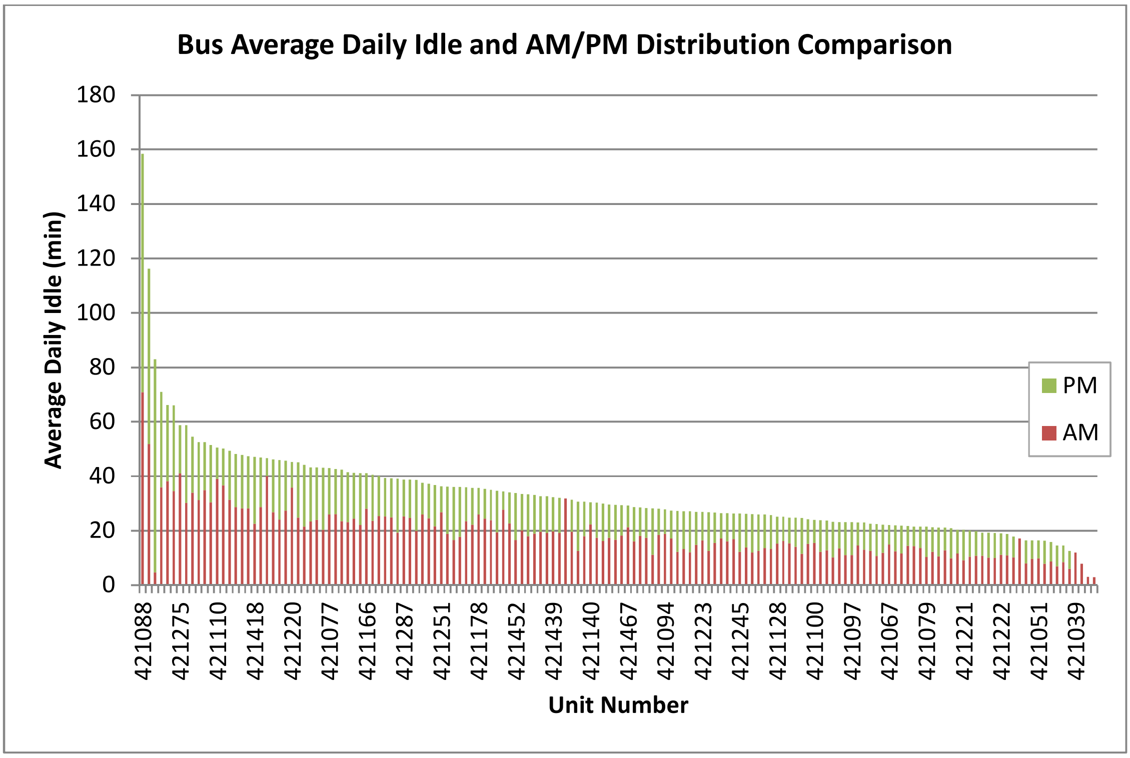

Figure 4.8: Distribution of Average AM/PM Daily Idle By Bus

Figure 4.9 shows the bins for the average amount of idle time in the AM and PM periods. The results of this figure are like splitting Figure 4.7 into two parts: morning and afternoon idling. Only 15 buses (10%) averaged more than 15 minutes in the PM. About 90% of the buses idle less than 15 minutes per day in the afternoon. About 69% of buses idle in the morning, averaging between 10 and 25 minutes per school day morning. Very few (5) buses average more than 45 minutes in the AM or PM period. This graph shows that there are clearly more buses that have a longer average AM idle time than the average PM idle time.

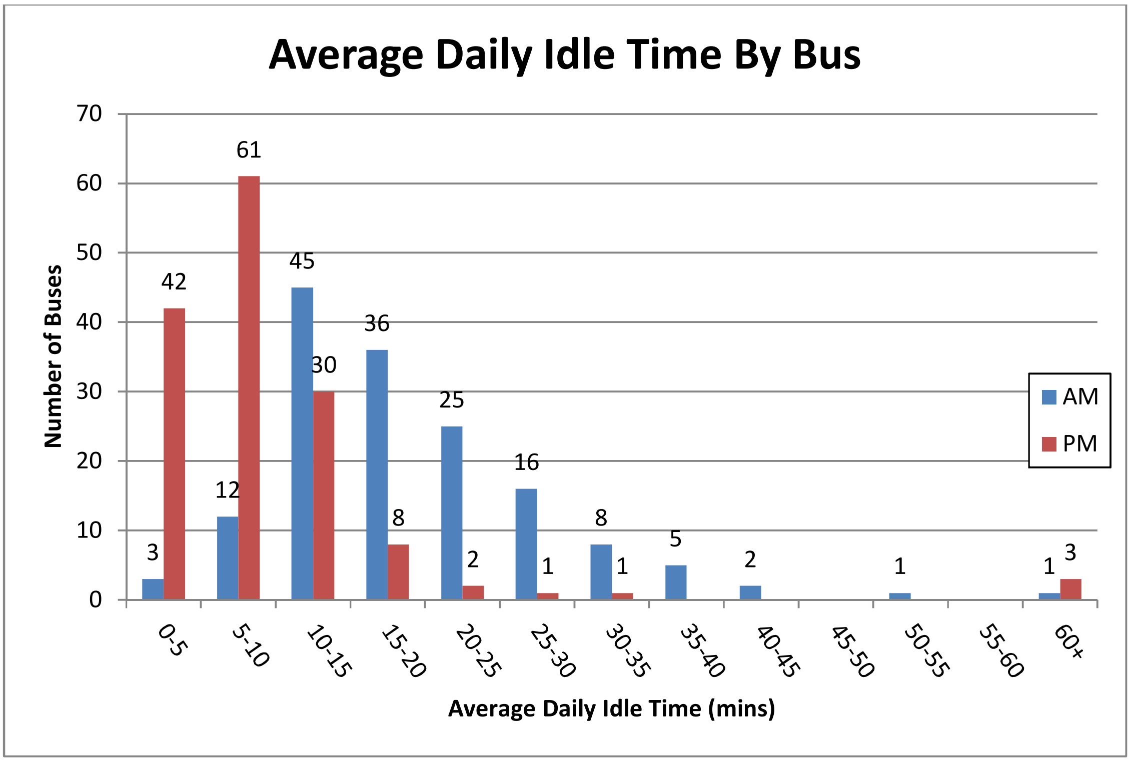

Figure 4.9: Average Daily Idle Time for Each Bus - AM and PM

4.5.3 Idle Summary By Time of Day

Figure 4.10 shows the distribution of idle events from the study period dataset over the course of the day, separated into 15-minute bins. The number of idle events peaks in the 7:00 AM to 7:15 AM bin with 2110 events occurring in that bin. The peak idle event hour is 6:45 AM to 7:45 AM in which 7,530 events occur. The PM peak 15 minute period is 3:45 PM to 4:00 PM with 1,830 idle events recorded. The PM peak hour is 1:45 PM to 2:45 PM with a total of 5,103 idle events. The distribution shows that most idle events are logged before starting the bus routes in the AM, and then in the afternoon, waiting to pick up students at schools to take them home. As recorded before, there are 18% more idle events in the AM than the PM.

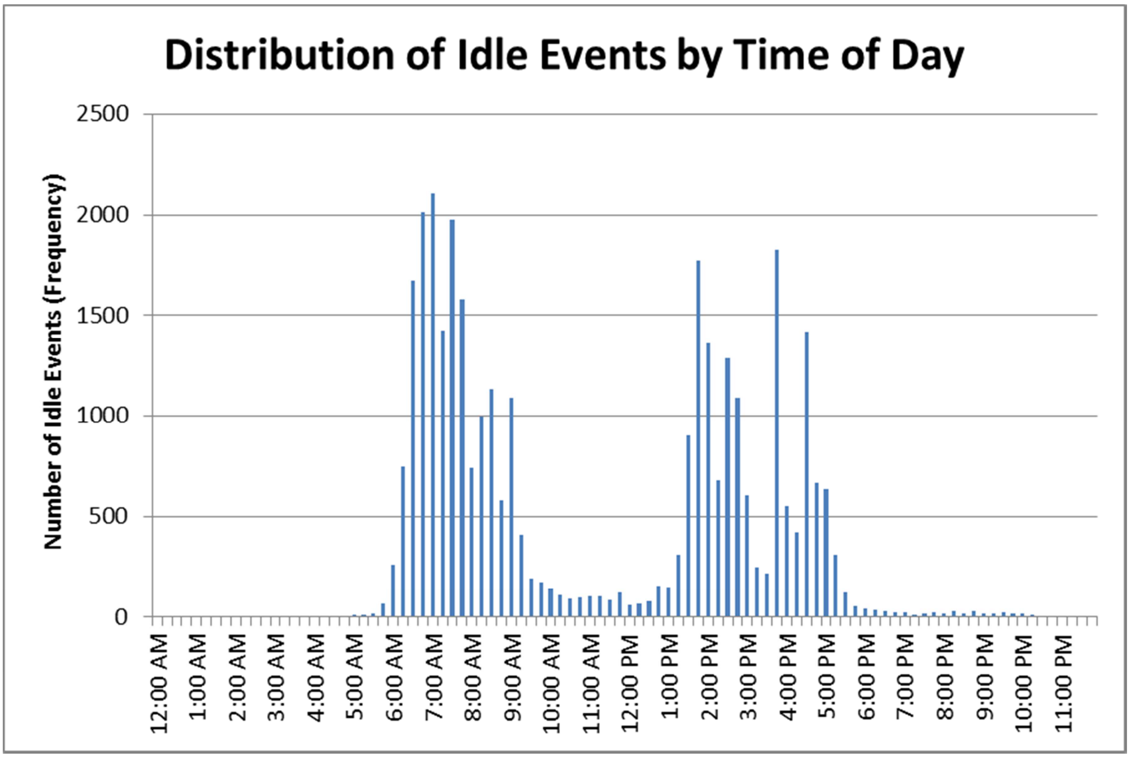

Figure 4.10: Distribution of Idle Events by Time of Day

Figure 4.11 shows the 40% more idle duration in the AM when compared to PM. Again, the idle event durations were broken down into 15 minute bins. The peak hour of idle duration does not overlap with the peak hour of idle events. The peak hour of idle duration occurred between 6:15 and 7:15 AM, with 849 total hours of idle. Comparing with the idle event peak hour, this shows that longer idle events start earlier in the morning and more idle events occur closer to the start of school. The peak 15 minute period was between 6:30 AM and 6:45 AM with 267 hours of idle. The PM peak 15 minute period 1:45 PM to 2:00 PM with 192 hours of idle. The PM peak hour of idling was 1:30 PM to 2:30 PM with 495 hours of idling. Again, this is a bit earlier than the peak hour for number of idle events. Inherently, the longer idling events start earlier in each period, so the number of idle events peaks at a later time than the duration of idling.

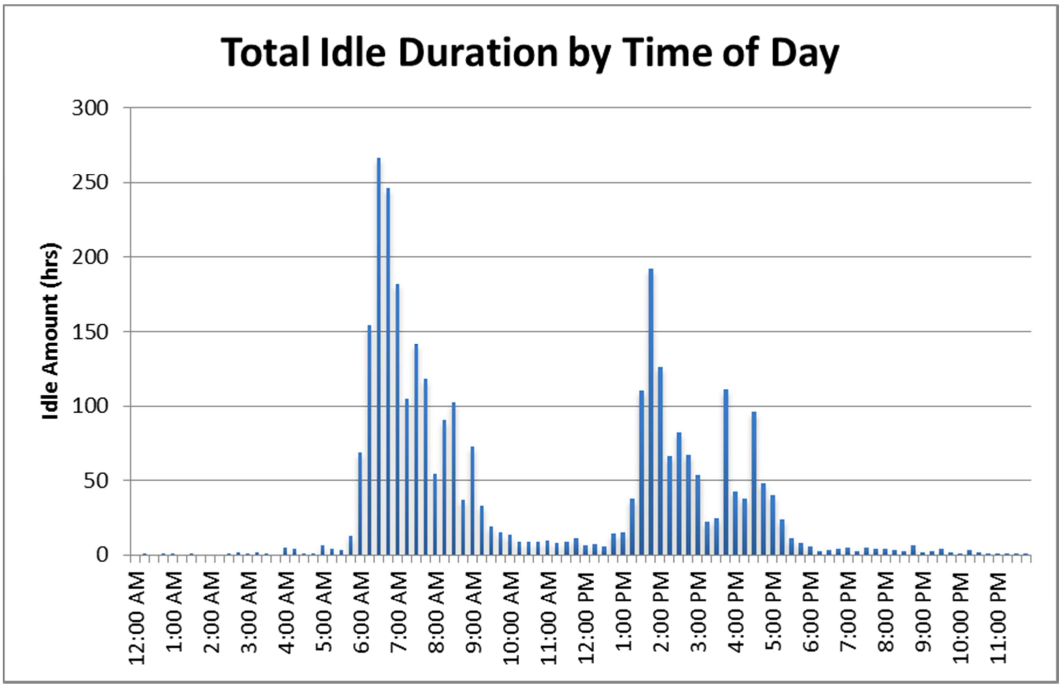

Figure 4.11: Total Idle Duration by Time of Day

Figure 4.12 shows the average length of idle events by the 15 minutes time bins. The chart's scale is dominated by a few early-morning events that averaged a much longer time than others. There were a total of three idle events starting between 4:00 AM and 4:15 AM, and they averaged 91 minutes in length. The 115 minute average idle event length from 4:15 AM to 4:30 AM was comprised of only two events. To be able to see a better distribution of the length of idle events over the course of the day, these outliers are removed and presented in Figure 4.13.

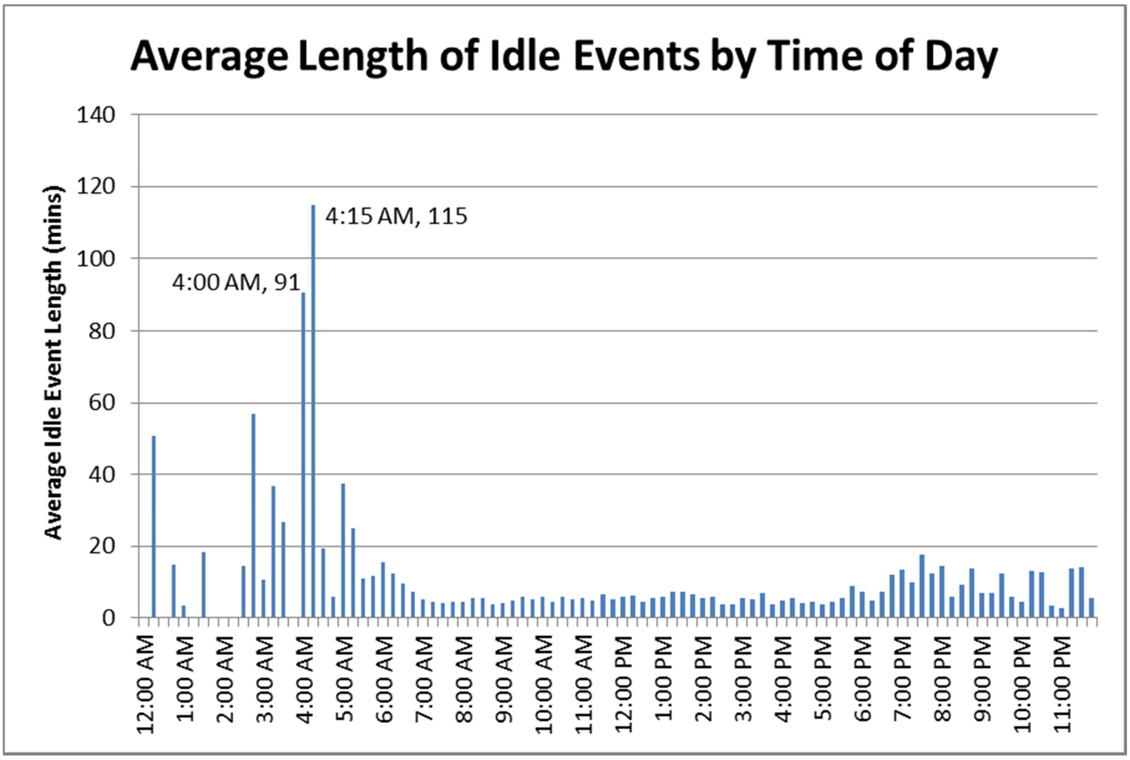

Figure 4.12: Average Length of Idle Events by Time of Day

Figure 4.13 shows the average length of idle events across a day, but only for those time bins in which at least 20 idle events were logged to get a better representation of the average value within those time bins. The length of idle events starting between

6:00 and 7:00 AM starts to decrease until reaching a relatively constant value that remains across the rest of the day. It is hypothesized that buses start idling before starting their routes in the morning, and continue to idle until starting that route. Because routes have been optimized by CCSD to have similar time durations and student loads, and because bus routes are designed to place the bus at the school immediately prior to school opening, buses all generally start at approximately the same time. Thus, idling events starting earlier will have a longer duration to make it to the start of the bus route time, which varies less than the start time of idling. The length of the idle events is notably short between 2:00 PM and 3:00 PM, when buses are likely dropping students off in the afternoon routes.

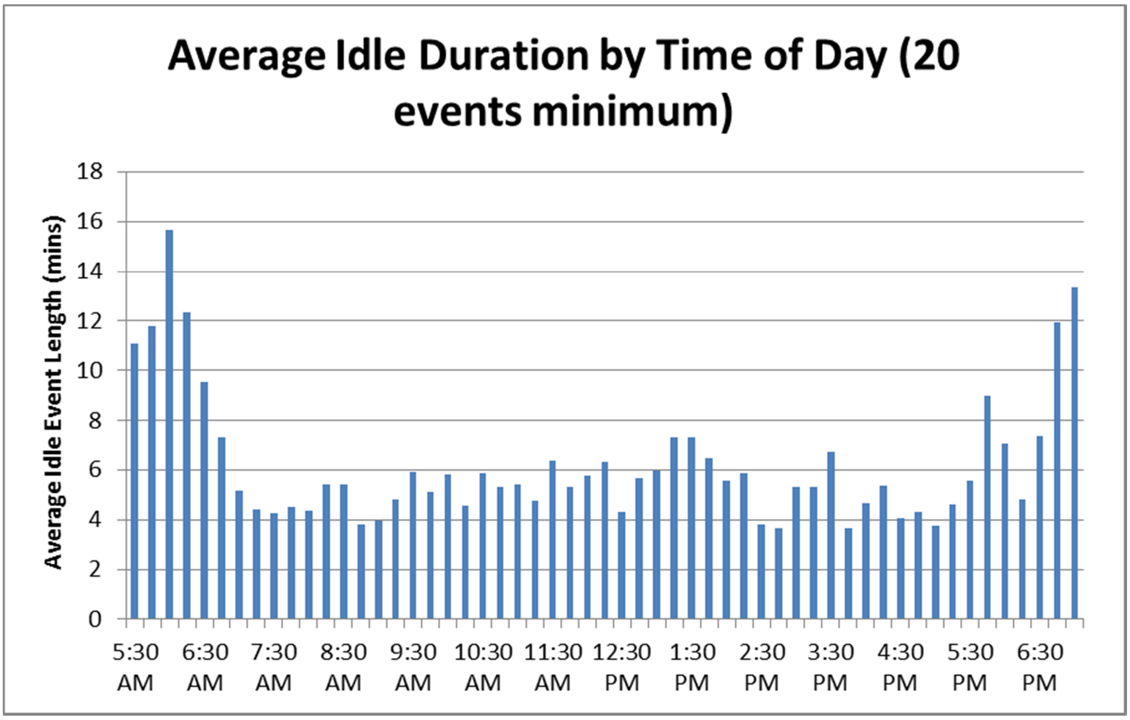

Figure 4.13: Average Idle Duration by Time of Day (Minimum 20 Events)

Figure 4.14 shows the number of unique buses idling at a given point of the day. The number of buses idling is greatest between 7:30 and 7:45 AM, and remains high until aftert 9:15 AM. The number of buses idling drops over late morning and midday before increasing to a high percentage again in the afternoon. The number of buses idling between the 3:15 PM and 3:45 PM dips likely due to afternoon routes being run. The percentage on the secondary ordinate axis is the percentage of total fleet buses starting an idle event within a specified time period. For example, to predict the number of buses that will log an idle event between 1:00 and 1:15 PM for a 1000-bus fleet, the percentage at the 1:00 PM datapoint, or 37%, can be multiplied by the number of vehicles operating in the fleet. Approximately 370 CCSD buses will log an idle event during this time period. The red line shows the percent of the total fleet idling: the number of unique buses idling at a given time point divided by the total number of buses, 193.

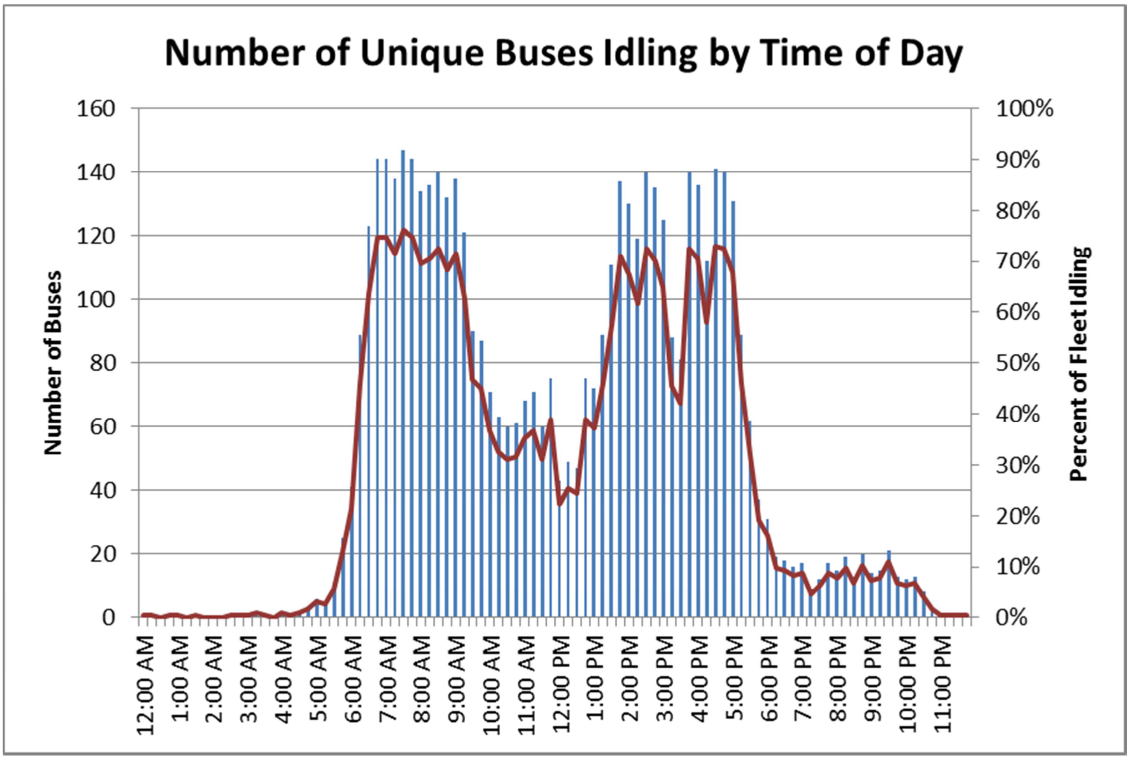

Figure 4.14: Number of Unique Buses Idling by Time of Day

4.5.4 Idle Summary by Month and Weather Condition

To assess the effect that time of year may have on the amount of idling, weather conditions can be examined in the context of monitored idling. Given that the baseline study began at the end of February, temperature generally increased over the course of the study period. Figure 4.15 shows the total daily idle for the entire instrumented fleet. The red line is the daily high temperature, the gray line is the daily average temperature, and the blue line the daily low temperature. This color format is consistent throughout the figures containing temperature information. The high, average and low temperatures generally increase of the course of the study as spring progresses, while the amount of idling generally decreases. This can be easily shown with lines of best fit, which have been removed for chart clarity. The average high at the start of the study period was 65 and 85 at the end of the study period. The average low was 40 to start the study period and 60 at the end of the study period. To visually draw these lines, use the right axis for temperature. In the last week of March, the high temperature never reached 55 degrees, with lows in the mid to high 30's. That week corresponds with the highest total amount of idle for a week. Visually one can see that the total amount of daily idling decreases over the study period. The weeks starting May 2nd and May 16th show a significant dip in weekly temperatures, and a corresponding increase in total idling on those weeks. This chart suggests that amount of idling, in contrast to the number of buses idling, could be a function of temperature.

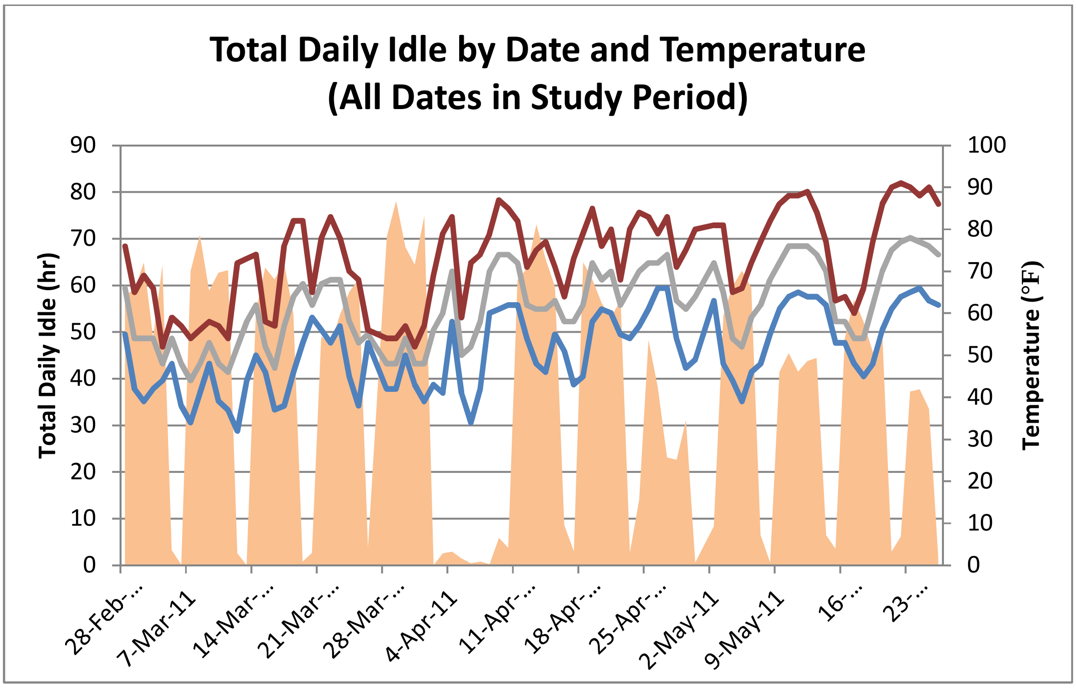

Figure 4.15: Total Daily Idle for Study Period

Figure 4.16 shows the average daily idle per bus plotted with temperature on regular school days. The chart for regular school days shows that average amount of idling per bus could also be a function of temperature, on weeks starting on March 21st, March 28th, April 25th, May 2nd, May 16th, and May 23rd, a change in temperature appears to be inversely related with the average amount of idling per bus that week.

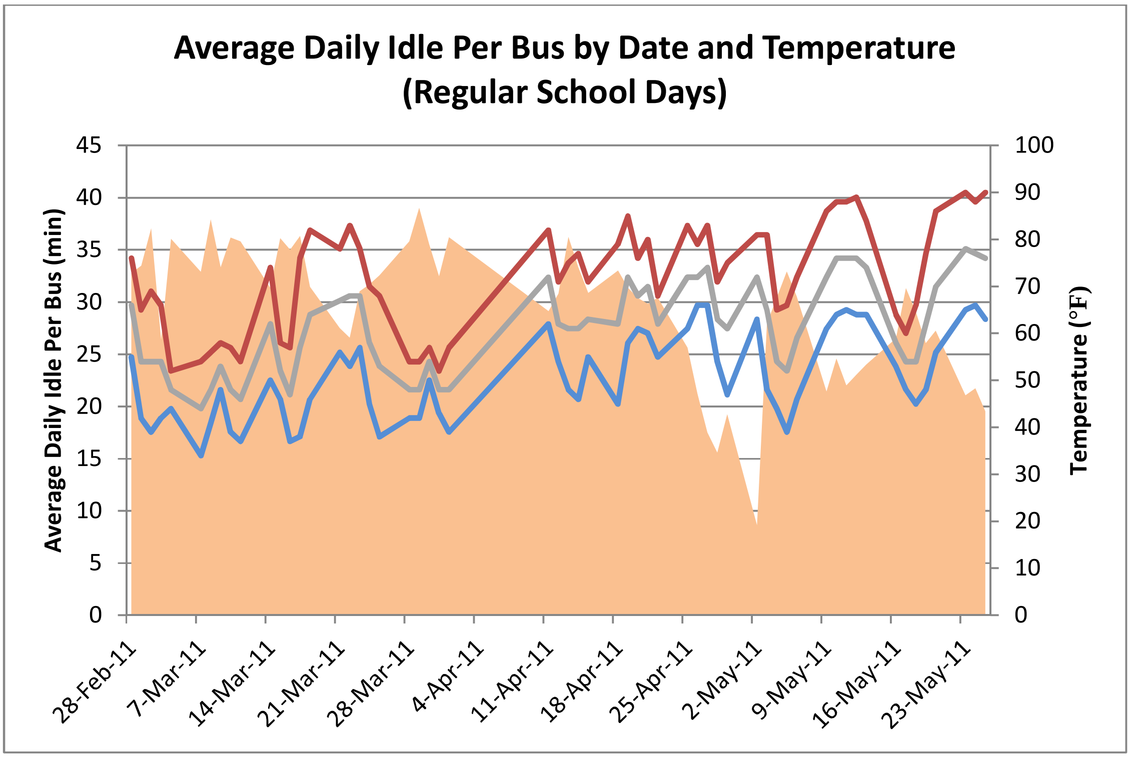

Figure 4.16: Average Daily for Regular School Days

The relationship between temperature and idling was tested using standard linear regression methods in Excel. Figure 4.17 shows the average daily extended idle per bus as a function of temperature. Only idle events longer than 120 seconds are used to calculate this average, as shorter events such as bus stops and intersection queingare not included since they should not be a function of temperature (bus stops are made and intersection queues are waited in, regardless of temperature). Again, the blue lines and circles are the low daily temperature data, the gray diamonds and line are the average temperature data, and the red triangles and line are the high daily temperature data. The linear regression lines appear to fit the data reasonably well. The equation of the regression line is shown below the chart and the coefficients for each line are presented in Table 4.7.

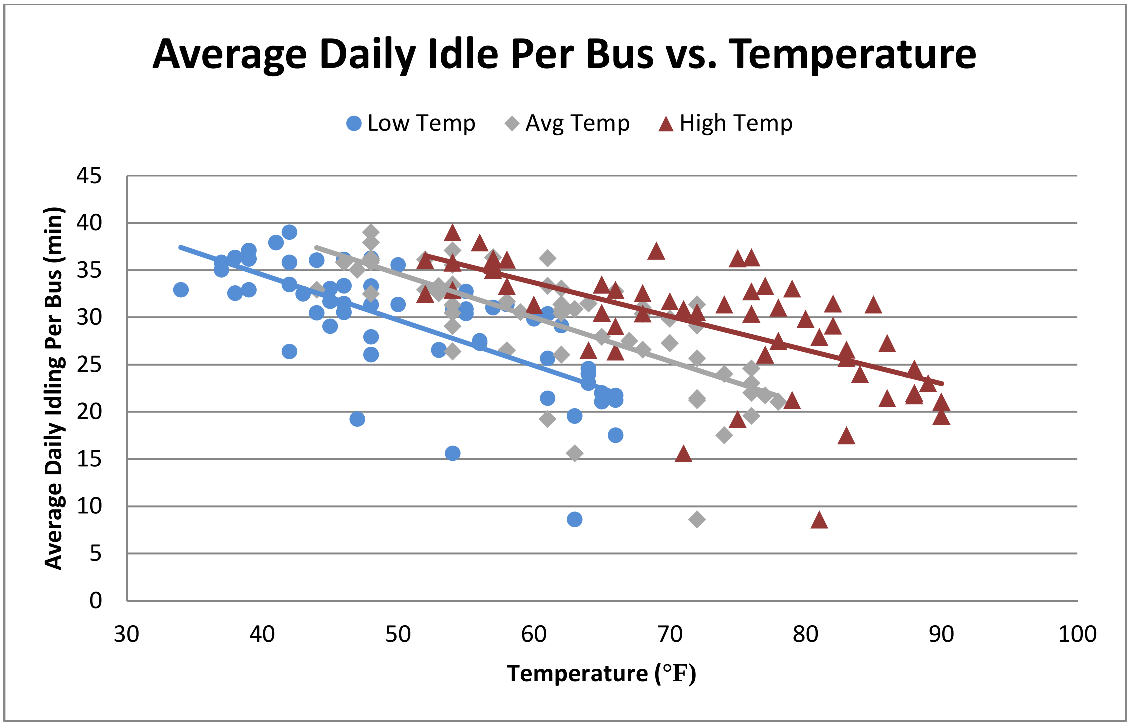

Figure 4.17: Average Daily Idle as a Function of Temperature

$$I_{av} = \beta * T + C$$

Where

I_{av} = Average Idle Time per Bus per Day (min)

β = beta fitting coefficient

T = Temperature (°F)

C = intercept adjustment constant

Table 4.7: Average Daily Idle Linear Regression Summary

Temp.	β	constant	R^2
High	-0.3562	55.056	0.4316
Avg	-0.4624	57.734	0.5243
Low	-0.4812	53.796	0.5208

After examining the chart and table, the average daily idling per bus appears to be most closely correlated with average or low daily temperature (R-square of 0.52). This does not seem unreasonable, given that more idling occurs in the AM and the low temperature is expected to have a greater effect than the high temperature on a given day in spring. These results and functions would likely change significantly as more data over the course of the year are collected. In the hot summer months of early August and September, the high daily temperature may control the amount of idling for buses equipped with air conditioning.

4.5.5 Idle Summary By Location

As a result of the GIS processing performed, the location of all idle events for the data range December 2nd, 2010 through March 31st, 2011 is shown in Figure 4.18 below. The size of the blue dot corresponds to the length of the idling event. As can be seen, most events cluster around specific locations. When plotted with the school and bus yard locations, the overlap is self-explanatory. The 114 school locations are not shown on the map for clarity. A graph of the full data range until May 26th was not available at time of writing, but since the number of idle events increases from 16,000 to over 32,000, the chart would likely be even more cluttered with idle activity. The relatively blank area in the center of the map is around the City of Marietta and their privately run school system and bus fleet.

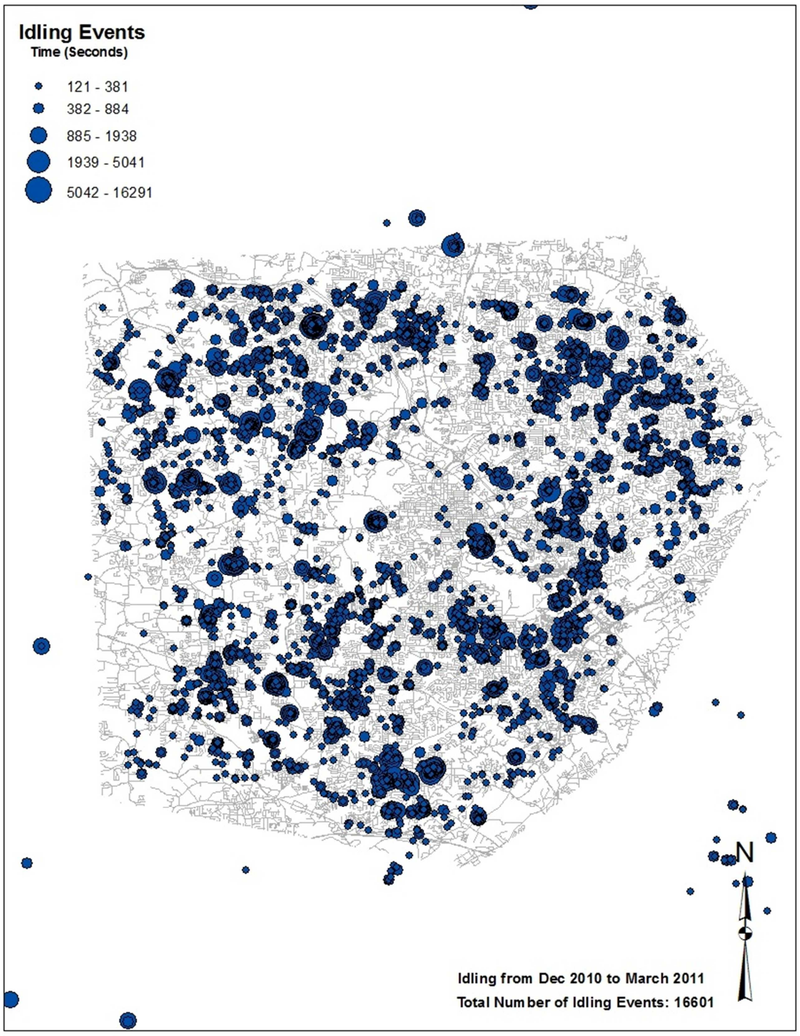

Figure 4.18: Idle Event Locations on Cobb County Map

Table 4.8 shows the breakdown of idle events by location type, for the full dataset of December 2nd, 2010 until May 26th, 2011. Over half of the idle events occurred at school areas or parking lots, which is also the idling location category that is most preventable. About 8% of all of the idle events occurred outside of Cobb County. A significant percentage of events occurred at intersections (16.2 %). Also coming in at 16.2% are the off-street events occurring in private parking lots and residences. Bus stops account for just over 4% of all idling events. Figure 4.19 shows the same percentages in pie chart format for comparison with another following graph.

Table 4.8: Idle Events by Location

Category	Description	Number of Idle Events	Percent
0	Out of Cobb	2,697	8.0
1	School Zone	17,736	52.5
2	Bus Stop	1,482	4.4
3	Intersection	5,470	16.2
4	On Street	916	2.7
5	Off Street	5,482	16.2

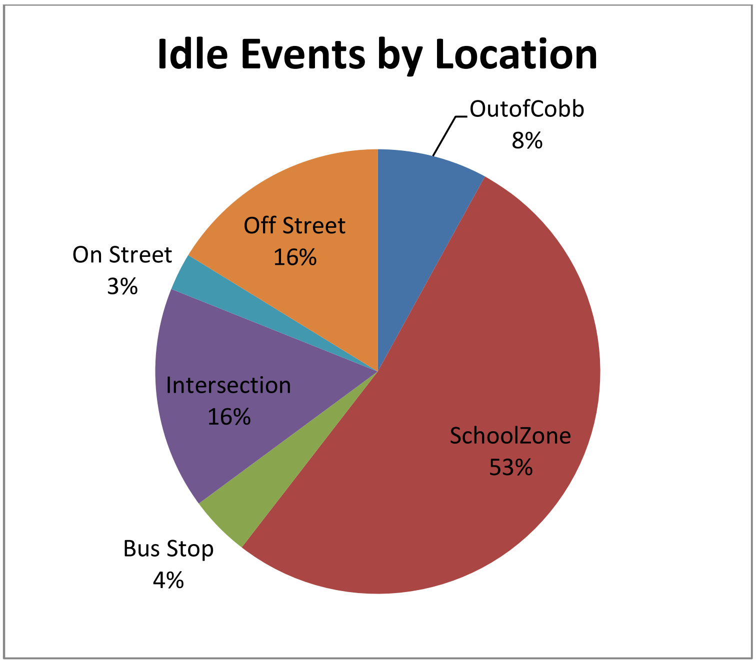

Figure 4.19: Idle Events By Location

Figure 4.20 shows the daily idle duration breakdown by location for buses. Although the school zone accounts for 53% of all idle events, 56% of bus idle hours occur in the school zones. All buses do not idle in each of the location categories each day. The average idle time behind the percentages in this figure are the average length of time spent in each location per day per bus, weighted by the frequency a bus idles in those locations (Figure 4.21). Because their overall share of idle time reduced from that of percent of idle events, bus stops and intersection events have significantly shorter average idle durations per event.

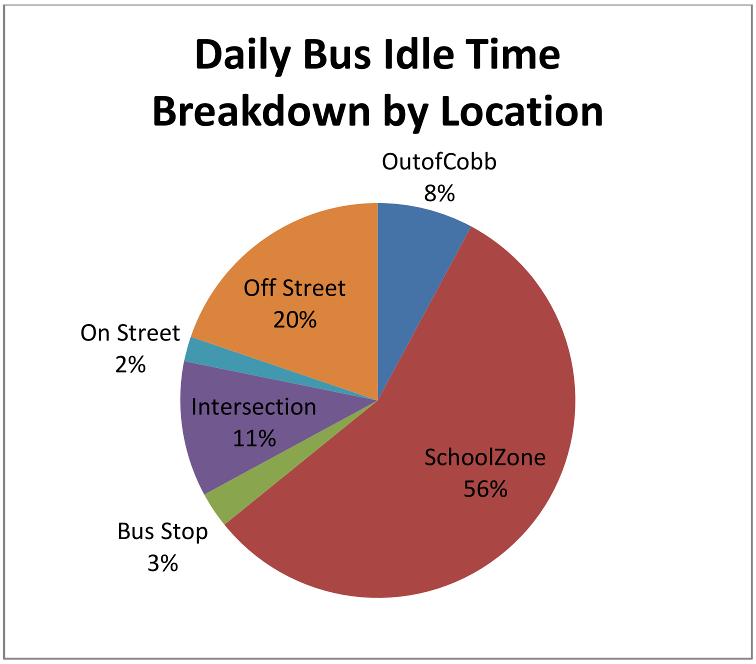

Figure 4.20: Daily Idle Time Breakdown By Location

Figure 4.21 shows that buses spend most of their idle time per day at school zones and off-street, which have been identified as the likely location for idling based on the characteristics of idling by time and school schedule. Buses generally do not idle at each one of these locations every day, so the average idle times in Figure 5.21 should not be summed for any analytical purposes.. The averages are the length of time a bus spends idling at a location *when they do idle at that location*, totaled by day.

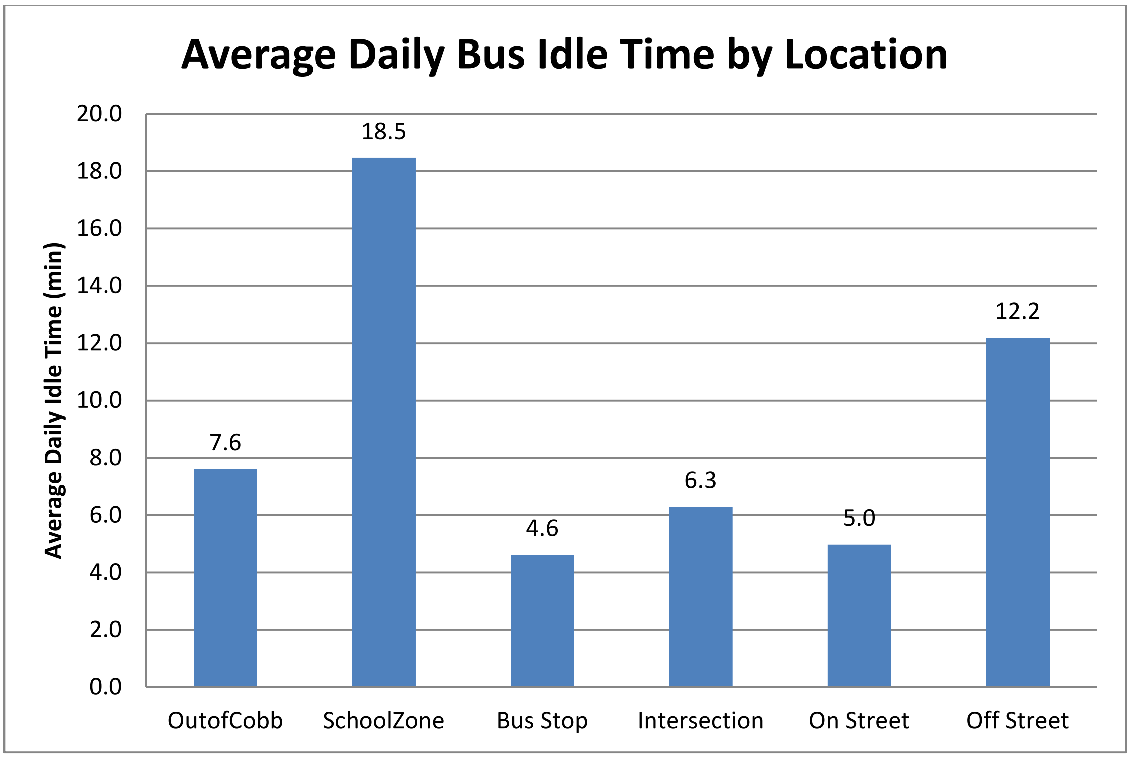

Figure 4.21: Average Daily Idle Time Per Bus By Location for the Buses that Idle at that Location

Figure 4.22 shows the average length of each idle event by location. Surprisingly, the school zone idle events are comparable in length to the other location average times. Inferring from the figure above, an average bus starts a six-minute idle event three times per day, for a total of 18 minutes of idling in school zones. The bus stop and intersection average idle event length are slightly longer than expected at 3.8 and 3.9 minutes respectively, comprise just 14% of the idle events. Plus, idle event lengths under 120 seconds are not included in this average.

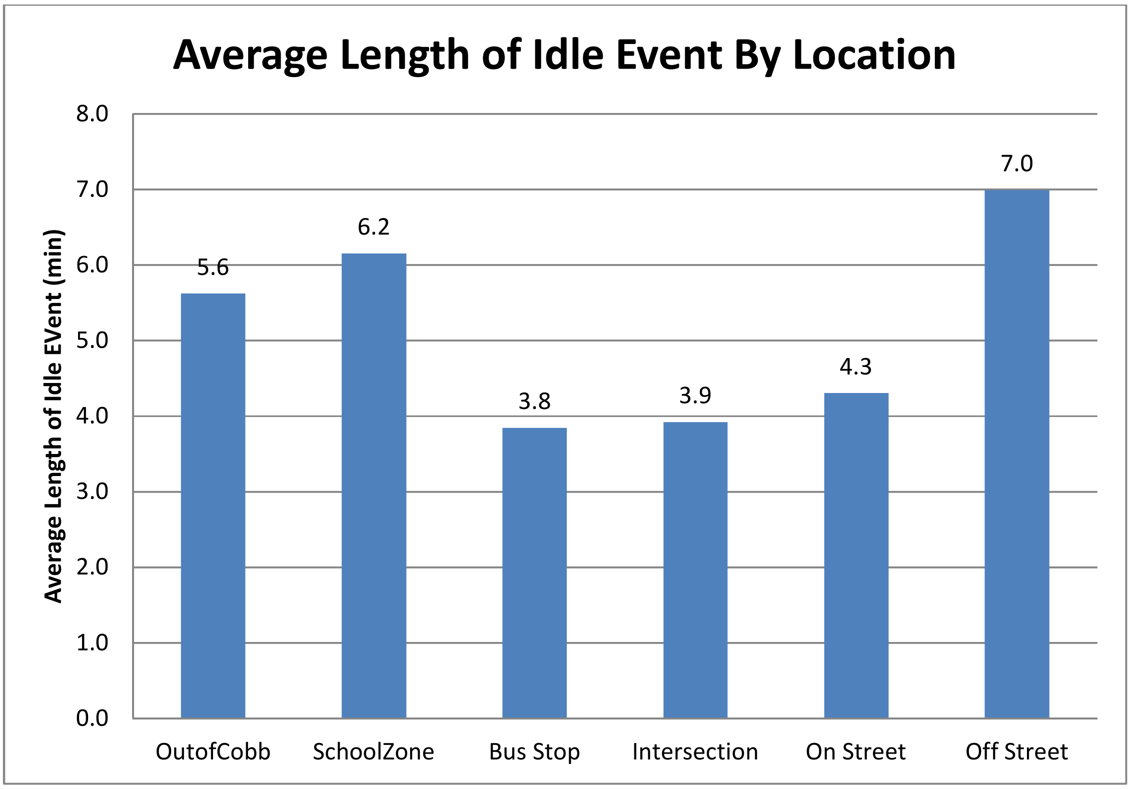

Figure 4.22: Average Length of Idle Event By Location

4.5.6 Heaviest Day of Idling to Date

The single day with the most amount of idling reported in the study period was March 29, 2011. On this day, there were 118 idling buses, of the 160 installed and 135 reporting at the time. On that day the 118 buses accumulated 77.5 hours of idle, or 0.66 hours (40 minutes) per bus. An average of almost exactly 4.0 idle events per bus was reached on March 29th. The reason for the heavy idling on is likely due to the weather characteristics of this regular school day. The AM temperatures were around 40° F, and the afternoon temperatures remained around 45° F in PM. The additional idling recorded on this day was likely due to bus drivers warming up the cabin. The days leading up to March 29th were also much warmer, with temperatures reaching into the 60's, so the low, all-day temperature on the 29th led to additional idling. This case reinforces the correlation identified between temperature and amount of idling.

4.5.7 Summary of Extended Idling Analysis

The average amount of idling per bus per day was found to be 29.7 minutes on regular school days, with 80% of the installed buses reported idle events 120 seconds or longer. Most bus idling occurs in off-street and school zone locations between the hours of 6:15 to 7:15 AM and 1:30 to 2:30 PM. Idling was shown to be moderately correlated with temperature, and can be predicted as a function of weather on a given day with reasonable aggregate-level accuracy.

Some additional analyses might be useful to further understand the nature and characteristics of idling for a local jurisdiction. Looking at idling by individual bus routes or regions might show discrepancies between schools or individual terrain or built-environment characteristics such as hills, valleys and intersection density. Collecting more seasonal data to see seasonal variance and to calculate an overall annual average idling amount is crucial to fully understand the idling of school buses in local municipalities. Collecting bus-level weekly or monthly fuel consumption and vehicle miles traveled (VMT) data could be used for a fuel efficiency before and after studies These studies are outlined in further detail in Section 7.4.

4.6 Total Idling and Vehicle Activity

The average amount of activity per bus, per school day was needed to scale the vehicle activity results to the proper analysis time scale (full year) and fleet size (480 buses). The data associated with weekends and holidays were eliminated when determining the average activity per school day operating mode bin. Table 4.9 shows the average activity in trips, miles, and hours of operation for all operating modes. The vehicle activity is broken down further in section 5.3, prior to estimating emissions.

Table 4.9: Average Daily Vehicle Activity

Average Daily Activity	Total Trips	Total Miles	Total Operating Hours	Total Idle Hours	Extended Idle Hours
School Days	17.1	39.5	2.7	1.1	0.50
Weekends and Holidays	0.2	0.6	0.03	0.01	0.006

CHAPTER 5

EMISSIONS MODELING METHODOLOGY

5.1 Current Emission Modeling for School Buses

Thompson, et al., (2010) conducted a review of HDDV emissions model across the United States. The study first identified the factors that affect emissions to cover which emission models take which factors into account. As discussed before emissions depend on a large number of variables; including roadway, traffic, driver, vehicle and environmental characteristics. School buses are typically built on truck chassis platforms with gross vehicle weight ratings (GVWR) of 19,500 – 33,000 pounds (M.J. Bradley and Associates, Inc., 2006). The full list of factors is shown in Figure 5.1.

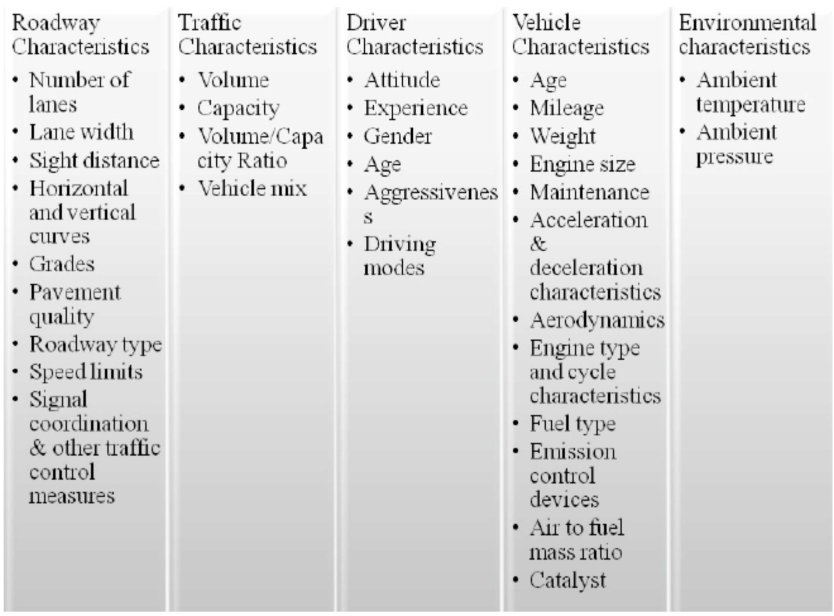

Figure 5.1: Factors Affecting Emissions (Thompson et al., 2010)

The current emission models for HDDV's fall into two basic classes: drive-cycle-based emission rate based models, and modal emission rate models. School buses are heavy-duty diesel vehicles, but the key difference between modeling for them and general HDDV's is their drive-cycle schedule, which is significantly different than most trucks and characterized by numerous stops spaced closely together.

Cycle-based emission rate models, such as the popular MOBILE6 and EMFAC, calculate average fleet vehicle emission rates based upon fleet composition, average traffic speed, temperature, fuel characteristics, etc. Emission rates by average speed or bhp-hr are derived from studies conducted in chassis or engine dynamometer test programs and include exhaust emissions from both cold and hot starts as well as evaporative emissions. The output of MOBILE6 is generally in grams per mile, averaged over a certain road link characteristics. Inputs include weather conditions, fleet characteristics such as model year distribution, vehicle activity parameters (VMT by speed, starts per day, trip lengths etc.) and fuel formulation and usage. The emission rates are calculated based on federal test procedure (FTP) drive cycles, adjusted for noted changes in vehicle emission rates when driven on other driving cycles (such as the New York City Cycle and High Speed Cycle). The cycles employed in developing speed correction factors by facility type may not accurately reflect the duty cycles of all vehicles, especially school buses. There is significant literature available on MOBILE6 and EMFAC emission models for the interested reader (TTI, 2006), (Zietsman, Bynum, Wieters, & Bochner, 2005), (Fitz, Winer, & Colome, 2003), (Hearne, 2003), (EPA, 2011) (CARB, 2010).

The cycle-based emission rate models are good for maintaining large emission inventories by region, but small scale, project-level emission impacts may be inappropriately modeled due to the averaging effects inherent in the model. Studies have indicated that EMFAC can be used to estimate emission inventories based on average traffic, roadway and weather conditions but may not be appropriate for estimating instantaneous emissions or the impact of traffic management strategies (Thompson, Unnikrishnan, Conway, & Walton, 2010).

In 2010, Marshall, et al., used MOBILE6 to estimate private vehicle and school bus emissions for a study focused on determining the mode choice faced by school children's parents and how school district assignment can affect the environment. Little detail is given on the emission modeling process used, and if local data were collected. Results are not separated by vehicle type, only totals by policy scenario for both private autos and school buses are shown (Marshall, Wilson, Meyer, Rajangam, McDonald, & Wilson, 2010). Emission estimates are shown for school buses exclusively, so the results have limited applicability to other jurisdictions.

In a Texas case study on school buses, MOBILE6 was used to estimate school bus emission rates of NO_x and $PM_{2.5}$, and questionnaires and interviews were used to estimate a school bus average speed of 20 mph as the operating condition for MOBILE6 analysis. Local data collected included vehicle age distributions, VMT, number of buses, and rural vs. urban setting. The study estimated that school buses in Texas produce about 0.8% of statewide mobile source NO_x emissions and 3.1% of $PM_{2.5}$ emissions (Zietsman, Bynum, Wieters, & Bochner, 2005). The importance of the study is that it is one of the few emission models run for school buses, but it fails to accurately model the operating characteristics of school buses by using a simple average speed rather than a range of operating conditions.

Modal emission rate models estimate instantaneous emission rates based on input parameters like speed, engine power, and acceleration. Some models have been integrated with traffic simulation models to evaluate the impact on emissions of traffic management strategies. MOVES, can be used as a cycle-based emission rate model by using internal cycle-related defaults provided with the software, or as a dynamic modal emission rate model.

Other modal emission rate models to note include Comprehensive Modal Emission Model (CMEM). CMEM was developed at UC Riverside and University of Michigan using data collected from second-by-second chassis dynamometer data. The test cycles were based on CARB tests, urban driving schedules, and real-world traffic cycles (Barth, Scora, & Younglove, 2004). CMEM could theoretically be used to model school bus emissions with a few modifications, but no study was found doing so.

Another modal model alternative is the Heavy-Duty Diesel Vehicle Modal Emission Model (HDDV-MEM), developed at Georgia Tech. HDDV-MEM has three main modules: the engine power, emission rate, and vehicle activity module. The engine power module predicts second based engine power as a function of speed, acceleration, weight, grade, drag, and drive train losses, and auxiliary power demand. The emission rate module estimates running emissions and idle emissions based on the zero mile level (ZML) emission rate, vehicle age, deterioration rate, and annual mileage (Feng, Guensler, & Rodgers, 2007). The ZML emission rates are based on MOBILE6.2 for running rates and EMFAC2002 rates for idle emission rates. HDDV-MEM is likely to be the most accurate method to estimate emissions when second-by-second vehicle activity data are available and linked to roadway characteristics at each second: most importantly road grade, provided that accurate gram/bhp-hr work-related emission rates are available for the vehicles in question.

5.2 MOtor Vehicle Emissions Simulator (MOVES)

MOVES was developed by the United States Environmental Protection Agency's (EPA) Office of Transportation and Air Quality (OTAQ) to model mobile source emissions. The MOVES model replaces MOBILE6.2 as the approved model for estimating on-road mobile source emissions in planning and environmental analyses. The MOVES model is based upon the analysis of millions of emission test results (EPA, 2009). The range of pollutants, vehicle types, fuels, and onroad activities modeled within MOVES is large, but not comprehensive. MOVES does not currently provide the ability to model non-highway mobile sources of emissions, and does not include default information about alternative fuels for use in long-range planning. The software is approved for use in state implementation plan (SIP) submissions and for transportation conformity analyses (except in California, where a different EPA-approved model is employed due to the nature of the California-certified fleet) (CARB, 2010).

The current version of the software, MOVES2010a, has made significant improvements to the emission modeling of heavy-duty vehicles, including school buses, over the Draft MOVES2009 version and MOBILE6.2. EPA analyzed data from more than 400 in-use trucks, rather than using certification tests for previously new 1990's engines. The software incorporates the emissions from heavy-duty diesel (HDD) crankcase ventilation and from extended idling, which were had not been studied significantly previously.

In MOVES, the user has the option of selecting criteria pollutants to model and specifying vehicle types, time periods, geographical areas, vehicle operating characteristics, and road types for modeling. Local data can be supplied for all of these model elements, and are required for certain modeling scales. The MOVES default database contains emission-relevant information from the entire United States. The sources for populating the default database include EPA research studies, Census Bureau vehicle surveys, Federal Highway Administration (FHWA) travel data, and other federal, state and local data sources (EPA, 2009).

5.2.1 Model Overview

MOVES estimates emissions from running, start, extended idle, evaporative, crank case, tire and brake wear, and life cycle processes (EPA, 2009). MOVES uses emission rates that vary by vehicle type and operating mode, which are classified by vehicle specific power (VSP) and current speed. The amount of time spent in each bin can be specified by default drive cycles, average link speed interpolation, or direct input of data.

MOVES can provide grams per hour emission rates for each pollutant process and school bus operating mode. These emission rates can then be coupled with bus hours travelled in each operating mode by the CCSD school buses to estimate the total overall emissions, on a per trip basis. The idle reduction estimate is then applied to the operating mode distribution of the CCSD buses and the difference between the total emissions is compared to determine the savings and effectiveness of the project.

MOVES is distributed free of charge on EPA's website. The model backbone is written in Java and uses MySQL database features. The program is able to modeling emissions for calendar years 1990 and 1999-2050. MOVES offers three scales for analyses: national, county, and project level. For our modeling purposes, the project-level scale is used. The project level scale requires the input of local data for analysis using the Project Domain Manager, a database import tool. The project level scale is the most detailed emission modeling methodology, as the user can specify the activity for a group of road links in the Project Domain Manager. The software requires the user to create what is called a run specification (runspec). Each runspec defines the vehicles being modeled, the geographic location, the fuel types, the activity, the time spans, the pollutants to model, and other custom options for output. MOVES uses the name source type to define a vehicle type. The 'source' refers to the source of the emissions. School buses are source type ID number 43. Other ID numbers can be found in Appendix B, the MOVES Decoder.

MOVES can run in two calculation types: Inventory or Emission Rates. Inventory calculates the total quantity of emissions within a region and time span, storing the output in the MOVESOutput database table. The Emission Rates calculation type, used in this project, calculates the emission rates for specific vehicle activities, such as grams per hour, or grams per mile, and stores the output in the RatePerDistance, RatePerProfile, and RatePerVehicle tables. The emission rate calculation type requires more run time, but the user is able to generate a lookup table of emission rates. The definition of a scenario for the lookup table calculation can include the vehicle age distribution so the lookup tables can be directly applied to fleets that match that profile.

Emission rate lookup scenarios do not specify the average vehicle speeds, so that vehicle activity can be post-processed with the appropriate operating bins. A MOVES project-level runspec can only be for one county, year, month, and hour.

The operating modes in MOVES are specified by vehicle speed, acceleration, and either vehicle specific power (VSP) or scaled tractive power (STP). VSP is used for the calculation of light-duty vehicles, while STP is used for heavy-duty vehicles. The equations for VSP and STP are third-degree polynomial functions of vehicle speed, with an additional term which differs between VSP and STP. The additional term for VSP includes an argument including the road grade to alter the vehicle specific power. A higher grade at a higher speed or acceleration will significantly affect the VSP. Higher VSP generally leads to a higher emission rate. The equation for VSP is:

$$VSP = \left(\frac{A}{M}\right) * v + \left(\frac{B}{M}\right) * v^2 + \left(\frac{C}{M}\right) * v^3 + (a + g \sin\theta) * v$$

Where A, B, and C are road load coefficients, M is the source mass factor in metric tons (midpoint weight for a given source type), v is the instantaneous vehicle speed in meters per second, a is the instantaneous vehicle acceleration in meters per second squared, g is the acceleration of gravity, and theta is the grade angle (EPA, 2010).

The operating mode bins for heavy-duty vehicles in MOVES are classified by scaled tractive power (STP), speed, and acceleration. The STP represents the vehicles tractive power, scaled by a constant factor for each different sourcetype to fit within the VSP-based operating mode bins for light-duty vehicles. The equation for STP is shown below. The road load coefficients in the equation factor in the tire rolling resistance, aerodynamic drag, and friction losses in the drivetrain (EPA, 2010).

$$STP_t = \frac{Av_t + Bv_t^{\ 2} + Cv_t^{\ 3} + mv_t a_t}{f_{scale}}$$

Where:

A = the rolling resistance coefficient [kW·sec/m],

B = the rotational resistance coefficient [kW·sec^2/m^2],

C = the aerodynamic drag coefficient [kW·sec^3/m^3],

m = mass of individual test vehicle [metric tons],

f_{scale} = fixed mass factor [metric tons],

v_t = instantaneous vehicle velocity at time t [m/s], and

a_t = instantaneous vehicle acceleration [m/s^2]

The STP equation does not directly account for the effects of road grade. This is a limitation of running emission modeling methods through MOVES. However, the instantaneous acceleration parameter could be adjusted to include the grade effect if desired.

EPA verified through e-mail correspondence that a value of 17.1 for f_{scale} for heavy duty trucks and buses is used (EPA, 2011). Table 5.1, taken from the MOVES technical background documents, shows the coefficients A, B, and C for school buses, highlighted in blue (EPA, 2010). The average mass of school buses is taken as the provided value of 9.0699 metric tons, or about 20,000 pounds. The rolling resistance coefficient, A, for school buses is set to 0.7467 kW-s/m, the rotational resistance coefficient, B, is 0, and the aerodynamic drag coefficient, C, is 0.002176 kW-s^3/m^3. These values were obtained from previous analyses for EPA's Physical Emission Rate Estimator (PERE).

Table 5.1: Resistance Coefficients for Source Types

Source TypeID	HPMS VtypeID	SourceType Name	Rolling Term A (kW-s/m)	Rotating Term B (kW-s2/m2)	Drag Term C (kW-s3/m3)	Source Mass (metric tons)	Fixed Mass Factor (metric tons)
11	10	Motorcycle	0.025100	0.000000	0.000315	0.2850	0.28500
21	20	PassengerCar	0.156461	0.002002	0.000493	1.4788	1.47880
31	30	PassengerTruck	0.221120	0.002838	0.000698	1.8669	1.86686
32	30	LightCommercialTruck	0.235008	0.003039	0.000748	2.0598	2.05979
41	40	IntercityBus	1.295150	0.000000	0.003715	19.5937	17.10000
42	40	TransitBus	1.094400	0.000000	0.003587	16.5560	17.10000
43	40	SchoolBus	0.746718	0.000000	0.002176	9.0699	17.10000
51	50	RefuseTruck	1.417050	0.000000	0.003572	20.6845	17.10000
52	50	SingleUnitShorthaulTruck	0.561933	0.000000	0.001603	7.6416	17.10000
53	50	SingleUnitLonghaulTruck	0.498699	0.000000	0.001474	6.2505	17.10000
54	50	MotorHome	0.617371	0.000000	0.002105	6.7348	17.10000
61	60	CombShort-haulTruck	1.963540	0.000000	0.004031	29.3275	17.10000
62	60	CombLong-haulTruck	2.081260	0.000000	0.004188	31.4038	17.10000

The second-by-second vehicle activity data stored on the server had already been broken down into individual trips for the CCSD fleet monitoring webpage. Each speed-time trace file representing a trip was processed for each second in the trip. The calculation of STP requires the speed and instantaneous acceleration of the vehicle. The acceleration was taken as the difference in velocity at times t and t+1, as shown in the equation below.

$$a_t = v_{t+1} - v_t$$

Where:

v_t = instantaneous vehicle velocity at time t [mph],

v_{t+1} = instantaneous vehicle velocity at time $t+1$ [mph], and

a_t = instantaneous vehicle acceleration [mph/s]

The velocities were then converted to metric for usage in the STP equation using the following equations:

$$v_t(m/s) \ = \ \frac{v_t(mph)}{2.23693629}$$

$$a_t(m/s^2) \ = \ \frac{a_t(mph/s)}{2.23693629}$$

The STP equation was then applied to each second of vehicle operation to calculate the scaled tractive power for each second of vehicle operation. A Perl script was used to assign the operating mode ID to each second of vehicle activity, based on the criteria specified in Table 5.2. For each trip, the total amount of activity (in seconds and miles) was summed by the operating mode bin and output to two separate files, one for seconds of activity in each operating mode bin and one for miles of activity in each operating mode bin. Idling activity (bin 1) is retained only in seconds of activity.

The operating mode bins for heavy duty vehicles using STP is shown in Table 5.2. There are 23 operating mode bins, with 0 being deceleration, 1 being idling, 11 and 21 are coasting, and all others are various combinations of cruise or acceleration. Operating mode bin 40 is expected to have the highest emissions for most pollutants, as the STP is greater than 30 kW and the speed is above 50 mph. This table was adapted from unpublished MOVES documentation from EPA. After discussions with EPA, the speed range for bins 11-16 was adjusted from $0 \leq v_t < 25$ to $1 \leq v_t < 25$ to avoid overlap with bin 1, idling (EPA, 2011). Deceleration or braking was defined as having an acceleration of less than or equal to -2.0 mph/s or having an acceleration of -1.0 mph/s for three consecutive seconds. A query on the ‘operatingmode’ table in the MOVES default database verifies this modification is used in the model runs.

Table 5.2: Operating Mode Classification (OpModeID)

Operating Mode	Operating Mode Description	Scaled Tractive Power (STP_t, skW)	Vehicle Speed (v_t, mph)	Vehicle Acceleration (a, mph/sec)
0	Deceleration/Braking			$a_t \leq -2.0$ OR ($a_t < -1.0$ AND $a_{t-1} < -1.0$ AND $a_{t-2} < -1.0$)
1	Idle		$-1.0 \leq v_t < 1.0$	
11	Coast	$STP_t < 0$	$1.0 \leq v_t < 25$	
12	Cruise/Acceleration	$0 \leq STP_t < 3$	$1.0 \leq v_t < 25$	
13	Cruise/Acceleration	$3 \leq STP_t < 6$	$1.0 \leq v_t < 25$	
14	Cruise/Acceleration	$6 \leq STP_t < 9$	$1.0 \leq v_t < 25$	
15	Cruise/Acceleration	$9 \leq STP_t < 12$	$1.0 \leq v_t < 25$	
16	Cruise/Acceleration	$12 \leq STP_t$	$1.0 \leq v_t < 25$	
21	Coast	$STP_t < 0$	$25 \leq v_t < 50$	
22	Cruise/Acceleration	$0 \leq STP_t < 3$	$25 \leq v_t < 50$	
23	Cruise/Acceleration	$3 \leq STP_t < 6$	$25 \leq v_t < 50$	
24	Cruise/Acceleration	$6 \leq STP_t < 9$	$25 \leq v_t < 50$	
25	Cruise/Acceleration	$9 \leq STP_t < 12$	$25 \leq v_t < 50$	
27	Cruise/Acceleration	$12 \leq STP_t < 18$	$25 \leq v_t < 50$	
28	Cruise/Acceleration	$18 \leq STP_t < 24$	$25 \leq v_t < 50$	
29	Cruise/Acceleration	$24 \leq STP_t < 30$	$25 \leq v_t < 50$	
30	Cruise/Acceleration	$30 \leq STP_t$	$25 \leq v_t < 50$	
33	Cruise/Acceleration	$STP_t < 6$	$50 \leq v_t$	
35	Cruise/Acceleration	$6 \leq STP_t < 12$	$50 \leq v_t$	
37	Cruise/Acceleration	$12 \leq STP_t < 18$	$50 \leq v_t$	
38	Cruise/Acceleration	$18 \leq STP_t < 24$	$50 \leq v_t$	
39	Cruise/Acceleration	$24 \leq STP_t < 30$	$50 \leq v_t$	
40	Cruise/Acceleration	$30 \leq STP_t$	$50 \leq v_t$	

The MOVES model adjusts the base emission rates collected from a number of sources for each vehicle type by factors associated with ambient environment, air conditioning (AC) usage, inspection and maintenance programs (I/M), and local fuel formulations. The temperature adjustments were based on emission test results from 12 heavy-duty diesel vehicles. The diesel humidity adjustment was taken directly from the

Code of Federal Regulations. The internal model adjustment is only applied to NO_x emissions (EPA, 2010). The I/M compliance factors were taken from the 2005 National Emission Inventory (NEI).

The AC effects on emissions are the most notable. The full AC adjustment is the factor used for a vehicle continuously operating the AC. Table 5.3 shows the factors for the heavy duty emission rates. NO_x emissions while idling may increase by more than a factor of six (626%) when the AC is operating, while CO emissions may increase by 13% and HC emissions by 8%. The huge percentage increase in NO_x emissions is mainly due to the very low value during normal idle operation (EPA, 2010) coupled with the marginal increase in engine load.

Table 5.3: Full AC Adjustment Factors for Pollutant Emissions

Pollutant	Operating Mode	Full A/C CF	Mean CV of CF
HC	Braking / Decel	1.0000	0.48582
HC	Idle	1.0796	0.74105
HC	Cruise / Accel	1.2316	0.33376
CO	Braking / Decel	1.0000	0.31198
CO	Idle	1.1337	0.77090
CO	Cruise / Accel	2.1123	0.18849
NOx	Braking / Decel	1.0000	0.19366
NOx	Idle	6.2601	0.09108
NOx	Cruise / Accel	1.3808	0.10065

However, the large adjustment factors are not expected to affect our results. The annual average low temperature was used to develop emission rates. The percentage of vehicles with the AC on is a function of the heat index, which depends on temperature and humidity. The annual average low temperature is below the heat index range shown in Table 5.4, and the expected AC on fraction is expected to be zero for the winter months analyzed, so the AC adjustment factor for our data will be one. For spring and fall months, the AC on fraction may increase, resulting in higher emission rates for HC, NO_x, and CO.

Table 5.4: AC On Fraction Based on Heat Index

Heat Index	AC On Fraction
67.44	0.000
70	0.089
75	0.251
80	0.399
85	0.534
90	0.655
95	0.762
100	0.855
105	0.934
110	1.000

5.2.2 MOVES Run Specification Parameters

The project-level emission rate run specifications are selected on the Scale panel. The Time Spans panel was set to include year 2011, the month of May, Weekdays, and the Hour of 8:00-8:59 AM. The month, weekday and hour information do not represent those actual values, the weather information input for these variables are based on annual averages. May and 8:00 AM were selected to reduce the number of modifications required to previous input files. In the Geographic Bounds panel, the region was set to Cobb County, Georgia and the domain input database (emissionrates) was specified on this tab. The On Road Vehicle Equipment panel specified the source use type of school bus and the fuel type of diesel as the only fuel/type combination to be modeled. The Road Type panel selection included all five road types: off-network, rural restricted access, rural unrestricted access, urban restricted access, and urban unrestricted access.

Although there are no rural roads in Cobb County, as classified by Georgia Department of Transportation (GDOT, 2010), all five types of roadways were selected to be modeled, again to reduce revisions to previous input files. The school bus emission rates do not vary by road type, contingent upon information entered about the road links in the Project Data Manager, which will be covered later. The pollutants selected for modeling included total gaseous hydrocarbon (HC), carbon monoxide (CO), particulate matter 10 and 2.5 (PM_{10}, $PM_{2.5}$), oxides of nitrogen (NO_x), and carbon dioxide (CO_2). The General Output tab was set to use units of grams for mass, Kilojoules (KJ) for energy, and miles for distance. The Output Emissions Detail panel was set with defaults except that the output was specified by source use type so that the road type distribution and average speed would not affect the results.

> "If "**Emission Rates**" are chosen on the **Scale** panel, output should be differentiated by "**Source Use Type**". Doing so allows VMT, Road Type Distribution, and Average Speed Distribution to become placeholders (i.e., they must still be imported, but their values do not impact the results)"… (EPA, 2009).

All of the MOVES input panel selections are shown in screenshots in Appendix D. To create operating mode emission rates, a separate runspec was created for each of the 23 operating modes because MOVES is not set to output emission rates by operating mode for a single run. MOVES is capable of providing disaggregate outputs for source use type, model year, fuel type, emission process, and road type. These separate output options are not mandatory. For example, in this project, the average emission rates were output for the fleet rather than by individual model year. That is, MOVES internally weights the separate emission rates for each vehicle model year in the specified fleet by their specified fleet distribution to generate an average fleet emission rate output. To obtain emission rates by operating mode, 23 separate runspec files were created. The operating mode distribution was set to 100% (‘1’) for one bin and ‘0’ of all other bins in each of the 23 separate runspecs. Since the operating mode distribution can vary by road type, hourdayID (a unique value specifying either weekday or weekend and the time of day), and pollutantprocessID (a unique value specifying a pollutant, such as NO_x, and a process, such as running exhaust), the operating mode fraction of ‘1’ was set for each combination of those variables, with all other operating modes set to 0 for a given runspec. This way, each MOVES run produced the emission rates for only one operating bin, separated only by pollutant processes.

5.2.3 MOVES Project Data Manager Inputs

The Project Data Manager lets users import information about the road links in the project scenario, link source types, the link drive schedules, fleet age distribution, fuel, operating mode distribution, meteorology, inspection and maintenance (I/M) programs, and off-network source type fractions. The link and off-network source type’s fractions were set at 100% for school buses. The fleet age distribution was set to match the profile of the instrumented fleet as shown in section 2.2.3. The Atlanta regional school bus distributions were provided by the Georgia Environmental Protection Division (EPD), but the age distribution for the actual 480-bus installed fleet was used in estimating emission reductions for this project. This difference turned out to be insignificant given fact that idle (but not all processes) emission rates are constant across model years 1990-2006, which includes all vehicles in the CCSD installed fleet. This also reduced the complexity of the emission savings calculation methodology, as the user no longer has to match vehicle activity by model year to a separate emission rate. The two fleet age distributions are shown in Figure 5.2.

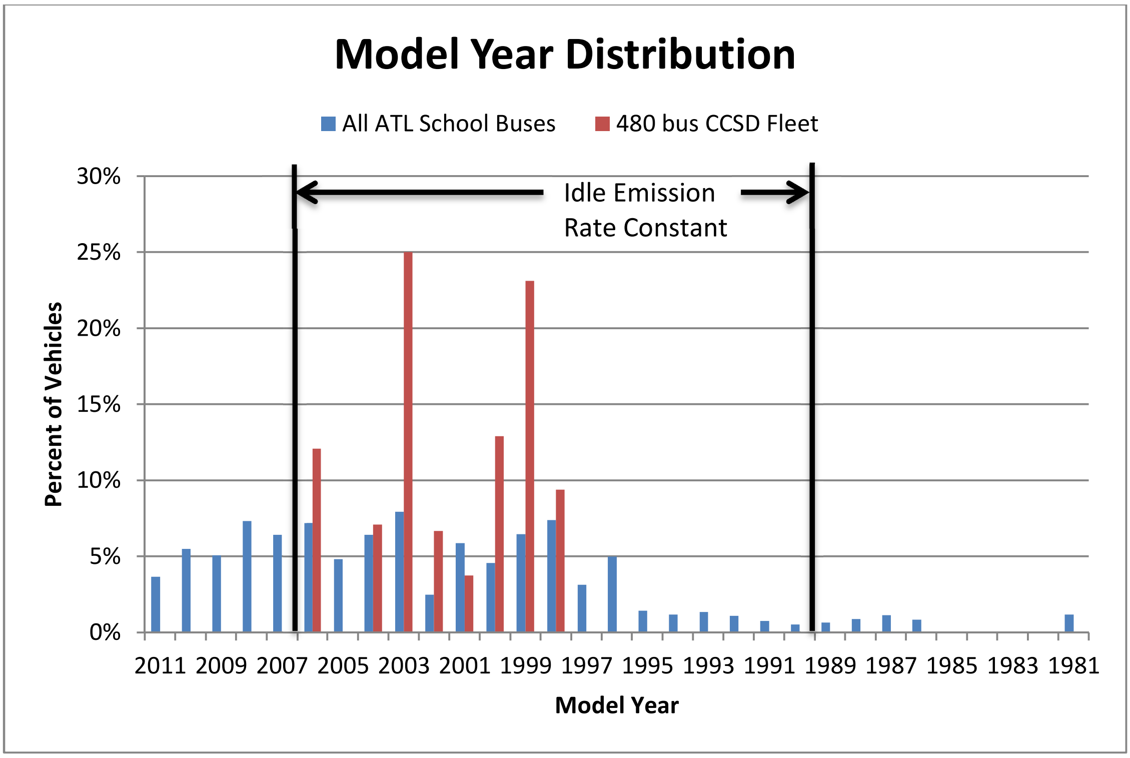

Figure 5.2: Fleet Age/Model Year Distribution

The fuel used by all CCSD buses is the standard Ultra-Low Sulfur Diesel (ULSD). The MOVES default fuel for school buses is ULSD, so no modifications were made to the fuel formulation.

Meteorology data were taken from two different sources. Temperature data were obtained from the National Weather Service Forecast Office of the National Oceanic and Atmospheric Administration (NOAA). The annual average low temperature was used so that the emission rates developed reflect the average over the course of the year. The low temperature was used rather than the average temperature because most school bus idling occurs in the morning (see section 4.5.3 for more details), and the average time of the low temperature of the day is very close to the average start time of the bus idle events. The annual average low temperature was taken from the station with longest history nearest Cobb County, from the Atlanta Hartsfield-Jackson International Airport (NOAA, 2006). The annual average low temperature used was 52.8 degrees Fahrenheit. This temperature value was arbitrarily assigned to the month of May and hourID 9 (8:00-8:59 AM); the emission rates developed are yearly averages, meaning MOVES uses this temperature to develop all emission rates, and it does not vary by time of year. The average annual humidity was taken from EPD-provided MOBILE6 to MOVES meteorological transfer files. The average annual relative humidity at 8 AM in Cobb County was 75.3 percent (EPD, 2008).

The emission rates for each operating mode bin inside the MOVES model are constant in gram/hour units for all activity that falls into a specific operating mode bin. When MOVES is run for one specific operating mode and one average speed, MOVES uses the average speed in the MOVES input file to create a gram/mile emission rate for the user (grams/hour divided by miles/hour). For each constant gram/hour emission rate, a difference in average link speed determines the amount of time spent on that link, and therefore the emission rate output in grams/mile. Hence, when MOVES is run for any specific operating mode bin and average speed, the gram/hour emission rate for that bin can be back-calculated by multiplying the gram/mile output emission rate by the input average speed (grams/mile * miles/hour). As such, users will find that no matter what speed is input to the MOVES model, the gram/hour emission rate for a specific operating mode will be a constant value.

Because MOVES requires that an average speed be entered, the average speed for each model run was set to the midpoint of each operating mode speed range. For all bins using a speed range of 1-25 mph (bins 11-16), the average link speed was set at 13 mph. For bins with an average speed of 25-50 mph (bins 21-30), the average link speed was set at 37.5 mph. For bins with an average speed of 50+ mph (bins 33-40), the average link speed was set at 50 mph. The gram/hour emission rates for each bin were then re-calculated from the gram/mile outputs using the applicable input average speed value. An average link speed of 13 mph was used for Bin 0, given that the decelerating/braking (Bin 0) will go through this speed range (25 mph to 1 mph) while braking. Operating mode bin 1 (idling) was also assigned an average link speed of 13 mph because MOVES does not output a value for idle emissions when a speed of zero is employed. Because idling accrues no VMT, the output for idling (bin 1) is drawn from the RatePerVehicle table, rather than the RatePerDistance table. The RatePerVehicle table defines the emission rates of the different pollutant processes of idling in terms of grams/veh/hr.

Three link input files were used for the 23 runspecs. The three files were differentiated by the average link speeds of 13, 37.5, and 50 mph. Each input file contained five links, one for each road type specified in the Road Type panel. The average grade for each link was set at 0, as this information was not available. The link volumes were set at 0 for all types except link type 5 (urban unrestricted, the majority of roads in Cobb County). Defining a link volume of 0 created null values for the emission rates output, but any range of volumes above zero did not produce a variance in the emission rates, which is expected. Road types 1-4 had volumes set to zero to avoid calculating duplicate emission rates and shorten model run time. The emission rates are constant across link types given that the model is running operating mode specific emission rates and no internal drive cycle weightings are being employed by MOVES to account for driving differences across roadway types.

After all of the inputs were entered in the Project Data Manager, the model was executed for each runspec. The output was taken from the RatePerDistance and RatePerVehicle tables in the output database, 'emissionratesout.' MySQL was used to export the results to Excel for analysis. The emission rates per mile were multiplied by the average link speed defined in the runspec to convert from grams/mile (which is based on the artificial links) to the gram/hour emission rates by operating mode bin. A series of average link speeds were run for a single operating mode bin to verify that, when multiplied back out, the emission rates in grams/hour were constant. The resulting emission rates are compared across bins and to the emission rates developed by other models.

5.2.4 Differences from Diesel Emissions Quantifier

EPA's online Diesel Emissions Quantifier (DEQ) estimates emissions savings from the implementation of various emission reduction strategies for diesel fuel vehicles. The emission rates and factors underlying the DEQ are from the National Mobile Inventory Model (NMIM). The DEQ also includes a health benefits estimator module for the particulate matter reductions. The tool is simply an estimator based on constant values, and should not be used for SIPs or conformity purposes. However, the DEQ is the standard method used to estimate emissions reductions and cost-effectiveness for

EPA grant proposals that involve diesel control strategies. The DEQ constant emission rates are averages that do not take into consideration a number for variables in a project specific fleet, such as operating mode distribution, local temperature and humidity, and inspection and maintenance programs.

The inputs to the DEQ include the annual idling hours per vehicle, in our case school buses. Other inputs required are vehicle type, fleet size, fuel type and consumption, VMT, and the idle reduction strategy information. Because the idle emission rate used in the DEQ background is constant across vehicle ages, all of the buses in the installed and full CCSD fleet were entered as the same model year. An example input screen from the DEQ online tool is shown in Figure 5.3.

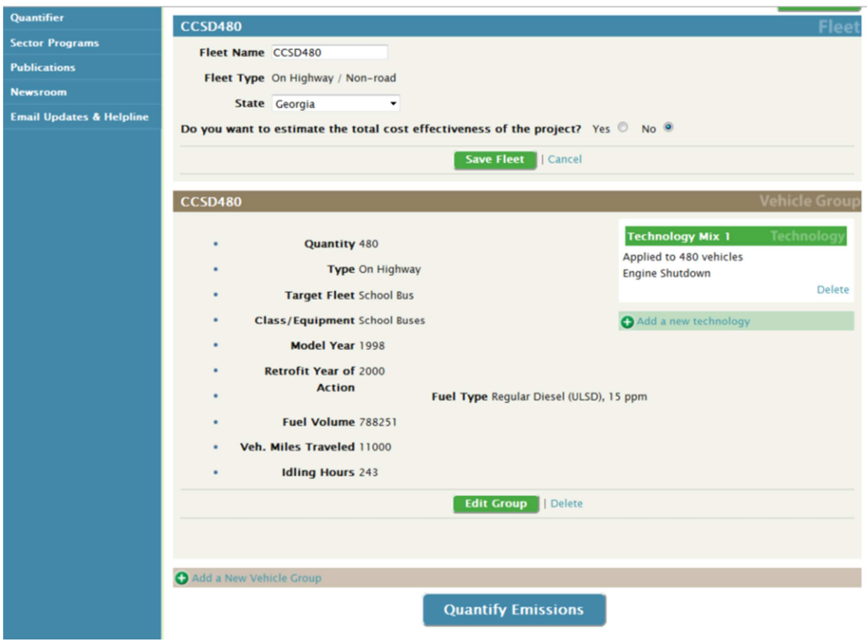

Figure 5.3: DEQ Input Screenshot

The emission savings of idle reduction techniques from the DEQ tool are compared to the savings from the MOVES-generated emission savings, to see the differences associated with running a simple estimator or a complex full-fledged emission modeling software. The emission rates are also back calculated from the vehicle activity and the total emissions output by DEQ, to compare the rates used in DEQ to the rates developed in MOVES.

5.3 Vehicle Activity by Operating Mode

Figure 5.4 shows the breakdown of the total amount of mileage accumulated while running in a certain operating mode bin, for weekends and holidays and school days separately. No mileage is accrued in bin 1, idling, because the vehicle does not move while idling. As expected, the majority of vehicle miles are accumulated in bins 21-30, which correspond with a speed of 25-50 mph and a range of STP. Bins 22 and 33 have low values because those bins are higher speeds with very low STP values. Given the nature of the STP equation with a velocity cubed term, very little activity is left in the low power categories when the speed is high. Bin 24 is the highest, which is moderate acceleration ($6 < STP < 9$) at medium-high speeds ($25 < v < 50$). The amount of vehicle activity is clearly much lower on weekends and holidays, so when calculating emission totals, non-regular school days should be calculated separately using the average values presented here.

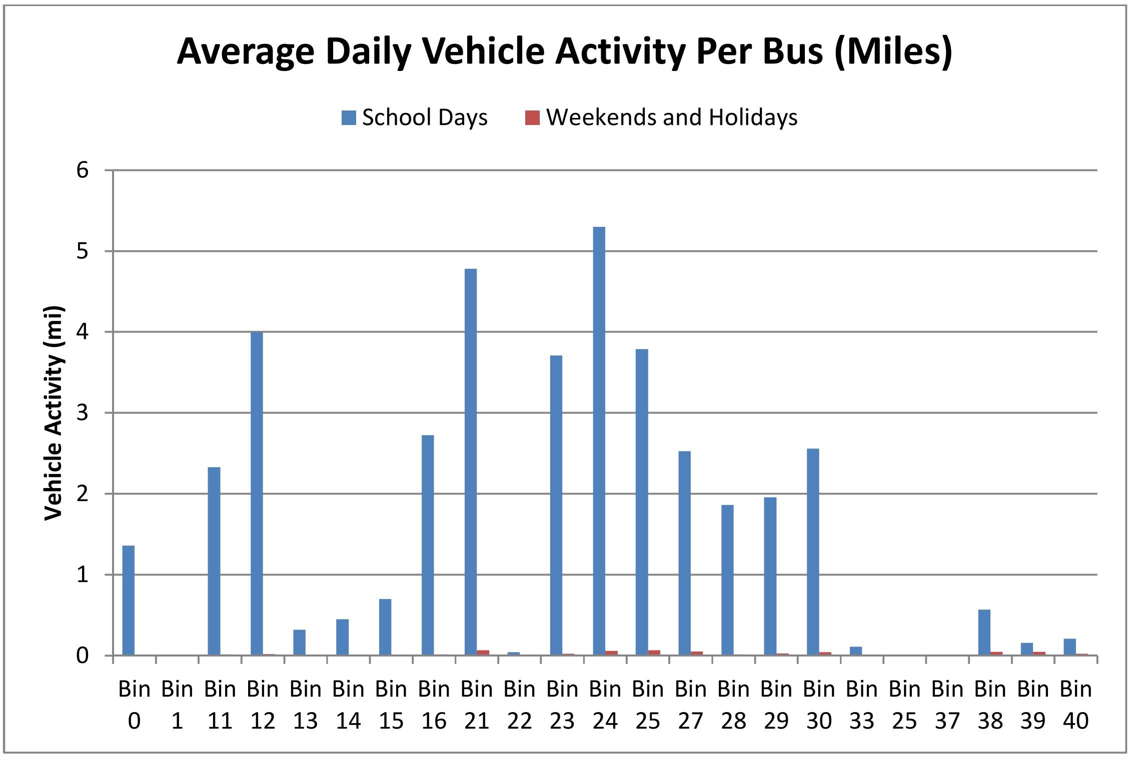

Figure 5.4: Average Daily Vehicle Activity Per Operating Mode Bin - Miles

Figure 5.5 shows the average daily vehicle activity in seconds of operation per bus on both weekends and holidays and school days. On both weekends and regular school days, the bin with the highest percentage of time spent within is bin 1, idling. On school days, a bus spends over 60 minutes idling. The MOVES idling bin, bin 1, requires a velocity in the range of -1 to 1 mph. The amount of idling reported in the vehicle activity includes all events less than as well as longer than 120 seconds, such as bus stops and intersections, and unnecessary extended idling. Idle events were defined as 120 consecutive seconds of speed less than 4 mph in the idle analysis in the following sections to remove operationally required periods of the bus being stationary. A small amount of the idling from an instantaneous speed value just over 1 mph from GPS wander likely falls into bin 12, where the speed is just over 1 and the STP equals 0. This amount of idling missed due to GPS wander was estimated to be a very small percentage of the dataset considered. The rest of the bins approximately follow the vehicle activity distribution for mileage, but the relationship is not linear. For every second a bus spends in a higher speed bin, a larger amount of VMT is accumulated than for each second at lower speeds. The amount of total idling constitutes over 38% of engine operating duration for the studied vehicles.

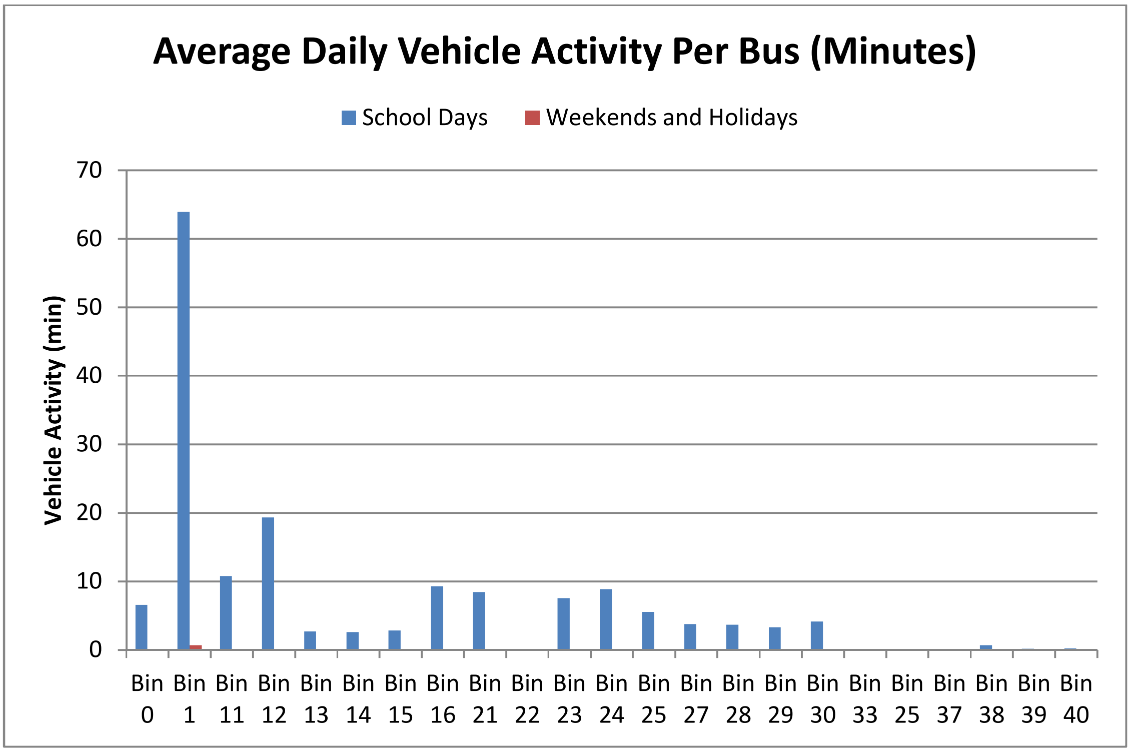

Figure 5.5: Average Daily Vehicle Activity Per Operating Mode Bin (Seconds)

Figure 5.6 shows the adjusted total estimated annual operation of the full 1150-bus CCSD fleet. Again, bin 1, idling is shown to be over 38% of all vehicle activity. The vehicle activity amounts shown in this graph directly affect the emission totals when multiplied by the emission rate by operating mode bin. The other bins that have a significant amount of activity are bin 12, low-speed high-power acceleration; bin 0, braking, bins 11 and 21, low and medium-speed coasting, and bins 16, 23, 24, 25, relating to a standard acceleration profile through a range of speeds and STP's.

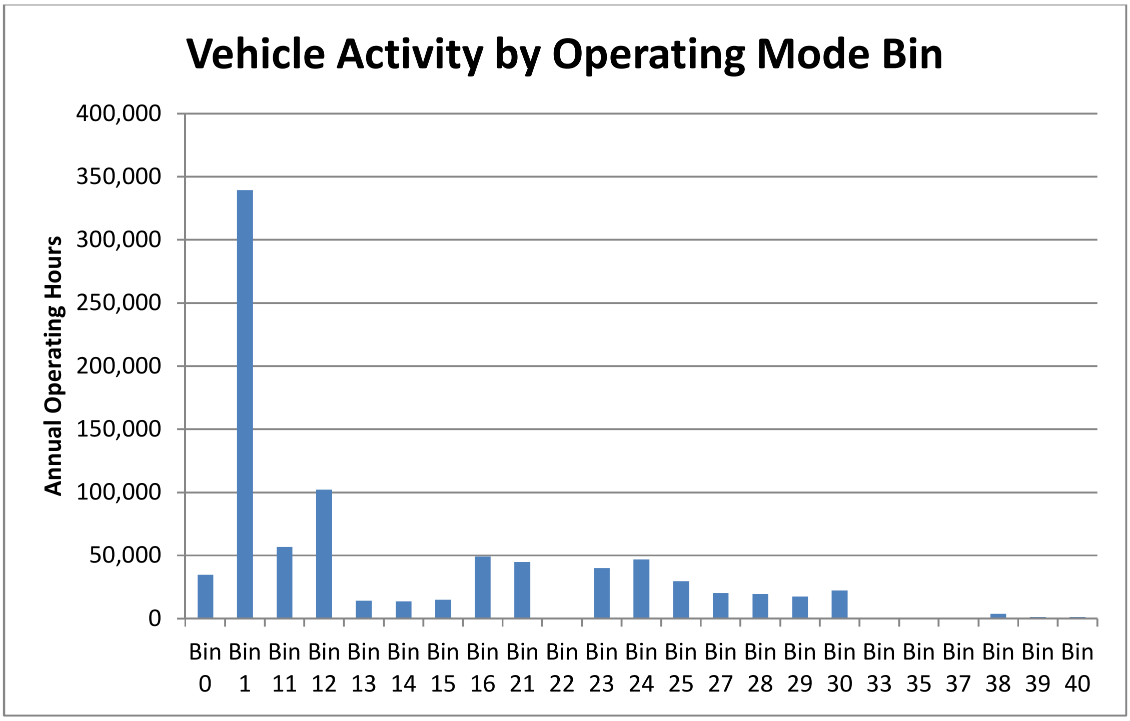

Figure 5.6: Total Estimated Annual Fleet Activity by Operating Mode Bin

5.4 Emission Rates

5.4.1 MOVES

The emissions rate lookup tables created from the MOVES run specifications are shown in this section. A summary for the key criteria pollutants is provided in Table 5.5, and the full range of emission rate lookups can be found in Appendix C. The emission rate for NO_x varies across the operating mode bins as a function of engine load. The maximum emission rate for NO_x occurs in operating mode bin 40, with a rate of 2725 grams per hour. The maximum rate for $PM_{2.5}$ is in bin 30, with a value of 198.5 grams per hour. The maximum rate for PM_{10} is similarly bin 30 with a rate of 192.6 grams per hour. Total gaseous hydrocarbons (HC) are relatively constant across operating mode bins. The rate for HC emission is 24.5 grams per hour and nearly increases to 32.1 grams per hour in the high-speed bins (bins 33-40) likely due to fuel enrichment under heavy load conditions. The carbon monoxide emission rate is similarly nearly constant across bins, but the higher speed bins have a slightly higher emission rate at 136.4 grams per hour. The total atmospheric carbon dioxide emission rate is highest in bin 40, followed by bin 39 with rates of nearly 369,356 grams per hour and 302,200 grams per hour respectively. These emission rates are shown graphically by bin in Appendix E.

Table 5.5: Emission Rates by Operating Mode

	Emission Rate (grams/hour)					
OpModeID	NOx	PM2.5	PM10	HC	CO	CO2
Bin 0	123.8	7.0	6.7	24.5	95.6	15,951
Bin 1	216.3	4.2	4.1	47.5	85.1	9,066
Bin 11	80.0	6.6	6.4	24.5	95.6	10,542
Bin 12	278.9	14.2	13.8	24.5	95.6	30,677
Bin 13	466.9	32.9	31.9	24.5	95.6	56,189
Bin 14	623.1	37.3	36.2	24.5	95.6	81,994
Bin 15	742.6	53.2	51.6	24.5	95.6	103,692
Bin 16	1049.6	53.2	51.6	24.5	95.6	142,627
Bin 21	51.5	7.5	7.3	24.5	95.6	8,503
Bin 22	320.8	22.8	22.1	24.5	95.6	39,430
Bin 23	521.0	30.7	29.8	24.5	95.6	65,394
Bin 24	728.1	48.6	47.2	24.5	95.6	94,647
Bin 25	930.7	67.1	65.1	24.5	95.6	121,702
Bin 27	1305.0	85.4	82.8	24.5	95.6	168,111
Bin 28	1576.7	118.9	115.3	24.5	95.6	235,356
Bin 29	1897.2	167.0	162.0	24.5	95.6	302,600
Bin 30	2318.8	198.5	192.6	24.5	95.6	369,845
Bin 33	263.2	0.0	0.0	32.1	136.4	35,078
Bin 35	962.0	33.3	32.3	32.1	136.4	107,266
Bin 37	1486.6	45.0	43.7	32.1	136.4	167,889
Bin 38	1824.2	61.7	59.8	32.1	136.4	235,046
Bin 39	2230.0	85.4	82.8	32.1	136.4	302,200
Bin 40	2725.6	100.9	97.9	32.1	136.4	369,356

The idle emission rates are constant across all operating mode input and average link speeds. The combination of start exhaust, the crankcase start exhaust, the extended idle exhaust, and the crankcase extended idle exhaust rates are shown in Table 5.6. The rates are in grams per vehicle per hour and closely follow the rates as specified in the 2009 MOVES Draft Heavy Duty Emission Rate Development documentation (EPA, 2009). Bin 200 is extended idle and was run in MOVES to determine if any differences exist between standard and extended idling. The CO_2 emission rate was not given for standard idling. In calculating total emission the rate for extended idling (60 minutes or more), 9,066 grams per hour is used.

Table 5.6: Idle Emission Rates by Idle and Extended Idle Operating Mode

	Emission Rate (grams/hour/veh)					
OpModeID	NO_x	$PM_{2.5}$	PM_{10}	HC	CO	CO_2
Bin 1	216.3	4.197	4.072	47.5	85.1	0
Bin 200	216.3	4.203	4.077	47.5	85.1	9,066

Table 5.7 shows the base idle emission rates from the draft 2009 MOVES document (EPA, 2009). The base idle rates are slightly higher than those calculated in the MOVES runs because they are the base rates, and were not adjusted for temperature, humidity, air conditioning, and fleet age distribution. The NO_x emission rate for MY 1990-2006 is 227 g/hr. The HC rate is 56g/hr and CO is 91 g/hr, compared to the project-specific MOVES-calculated rates of 216 g/hr for NO_x, 47 g/hr for HC, and 85 g/hr for CO. The lower rates are likely due a slightly newer than average bus fleet. The emission rate outputs from MOVES for this project appear reasonable by comparison to the base 2009 MOVES rates.

Table 5.7: MOVES Heavy-Duty Vehicle Base Idle Emission Rates

Base Idle Emission Rate (g/hr)			
	Pollutant		
Model Year	NO_x	HC	CO
Pre-1990	112	108	84
1990-2006	227	56	91
2007 and later	201	53	91

5.4.2 DEQ Emission Rates

DEQ assumes default values of 13,000 VMT, 1,597 gallons of fuel, and 270 idling hours per year per school bus (NCDC, 2010). These values were adjusted to match the characteristics of the CCSD fleet, which are 11,000 VMT, 1,642 gallons of fuel, and 194 idling hours per year. The DEQ user guide states that the idling emission rates for CO and HC are zero (NCDC, 2010).

After running the DEQ software, the emission rates were back calculated from the emission total results. The total emissions per year for each pollutant were divided by the total hours of operation for the analyzed fleet to get the grams/hour rate for comparison with MOVES. The PM rates are reported together in DEQ, and they assume that 96% of all PM is fine or $PM_{2.5}$ (NCDC, 2010). Therefore, the MOVES PM rate shown is for $PM_{2.5}$. The DEQ emission rates are significantly lower than the MOVES emission rates (Table 5.8). The overall emission rate from MOVES is the total emissions divided by the total hours of operation for each pollutant.

Table 5.8: Overall Emission Rates: MOVES and DEQ

Overall Emission Rates (grams/vehicle-hr)			
Pollutant	**DEQ**	**MOVES**	**% Difference**
NO_x	181.95	491.03	170%
PM	3.45	29.30	748%
HC	10.21	33.49	228%
CO	26.60	91.89	245%
CO_2	21,775	59,750	174%

Although the emission rates (and therefore savings) are much higher in MOVES than DEQ, the latest approved model was desired to be used when determining the emission rates. Also, the MOVES rates are likely more accurate, since they are based on the operating mode distribution of an actual vehicle fleet, and include adjustments for temperature and a number of other factors.

Table 5.9 shows the comparison for the idling emission rates in terms of grams per hour. Again, the MOVES rates are higher than those in DEQ. The HC and CO emission rates were not able to be calculated, DEQ did not output any HC or CO emissions from idling despite entering a savings percentage defined as the amount of emissions from non-start processes. Using a value of 6.943 pounds/gallon of diesel and a 12/44 ratio for carbon and carbon dioxide molecules, The CO_2 emission rates here translate to 0.44 gallons/hour (DEQ) and 0.78 gallons/hour for MOVES. Both tools seem to use a constant fuel consumption ratio to determine the CO_2 emission rate, which calls for additional modeling accuracy. The idling emission between MOVES and DEQ rates are much closer than the overall rates, since the idling emission rates are calculated as constant over model years in both programs. However, the large discrepancy between DEQ and MOVES emission rates may be a significant issue with respect to control strategy emission reduction potential and comparative cost-effectiveness evaluations when the DEQ is required for use in the preparation of grant proposals by EPA.

Table 5.9: Idling Emission Rates: MOVES and DEQ

Idling Emission Rates (grams/hr)			
Pollutant	**DEQ**	**MOVES**	**% Difference**
NO_x	144.1	216.3	+50%
PM	3.9	4.2	+8%
HC	n/a	47.5	n/a
CO	n/a	85.1	n/a
CO_2	5,039	9,066	+80%

5.4.3 Idle Emission Rates from Other Studies

A study by the Texas Transportation Institute (TTI) collected emissions data from five diesel school buses with Portable Emission Measurement Systems (PEMS) from the Texas fleet (model years 1987-2004) with two different Low-Emission Diesel (LED) fuels. The sulfur content of the two fuels were 0.3 ppm and 5 ppm, classifying them both as Ultra Low Sulfur Diesel (ULSD) fuels. The study also used local data to run MOBILE6 to perform an emission rate comparison. The findings of the study suggest much lower emission rates than would be calculated using MOVES (26 g/hr for NO_x, 2.2 g/hr for HC, and 4.4 g/hr for CO). The weather on the test days (July 11-16, 2006) ranged in the high 70's to mid-90's (TTI, 2006). However, the temperature used in the development of the MOVES emission rates was 52 degrees, which partially explains the higher rates in the model. The study by TTI used generic drive cycles on a 6,000 foot level test track. Although care was taken to select representative drive cycles, the in-use GPS vehicle activity data in this study are the most accurate method for determining drive cycles and operating characteristics. The level test track (more representative of Texas than Atlanta metro) and long cruise periods likely left out grade-based high engine load events, which are a major contributor to all emission processes. In TTI's study, the buses were also not in cold start mode, they were warmed up for at least 20 minutes before each test run. The combination of these five elements: cleaner fuel, flat track, basic drive cycles, higher temperature, and the bus engines being warm are expected to account for the difference in the emission rates. The TTI study also developed idle emission rates in MOBILE6, and the results are significantly higher than the cycle tests. The author mentions that the drive cycle used in the MOBILE6 method is different, and the MOBILE6 model accounts for cold-start emissions, whereas during their test, only the first of each group of 7 runs was cold-start. Certainly, the study indicates that a much more detailed field study of school bus idle emission rates is warranted.

J.S. Kinsey performed an idle emission test on six diesel school buses in the northeastern US in winter 2005 to assess the effectiveness of shutting off the bus vs. leaving it running, under the assumption that hot restart emission rates are higher than continuous idling rates. The buses in the study were in the model year range 1997-2004, but used regular diesel with a sulfur content of 226 ppm, rather than the Cobb County standard ULSD, with 15 ppm maximum sulfur content. The study found emission rates for NO_x, CO and $PM_{2.5}$ to be slightly higher after restarting the bus. The calculated average emission rates (after hot-restart) were 78g/hr for NO_x, 31.8 g/hr for CO, and 0.34 g/hr for $PM_{2.5}$ (J.S. Kinsey, 2007). Continuously running emission rates were slightly lower. These rates are all significantly lower than the DEQ and MOVES idle emission rates, perhaps in part because the buses had DOCs and crankcase ventilation filtration systems installed, but additional field studies appear warranted to verify MOVES.

TravelMatters uses a rate of 8.2 pounds of CO_2 per mile for Class A transit buses in the MARTA fleet, which equates to 3,723 grams per mile, much lower than the DEQ and MOVES emission rates for school buses (TravelMatters, 2002). The emission estimator from TravelMatters is based on the Mobile6.2 model, with NOAA 2002 weather information and Federal Transit Authority (FTA) database data (TravelMatters, 2011). Transit agencies are typically under higher pressure to reduce emissions from their fleet as they are more publicly visible in terms of emissions. The study will show later that school bus emissions are just as significant, if not more significant, than those of transit agencies in metropolitan areas.

A study on modal emission rates of heavy-duty diesel vehicles went into detailed statistical analysis to assess the idle emission rates based on emissions data and matching engine load information about diesel transit buses and one truck tested in two separate tests in 2001 (Zhou, 2006). The idle mode was chosen as speed <- 2.5mph and acceleration <= 1mph/s. A bootstrap analysis was used to estimate the average emission rates. These are again for heavy duty trucks and transit buses, so the emissions may vary from school buses due to engine differences. The bootstrap analysis revealed very wide confidence intervals, which for NO_x and CO exceed the MOVES emission rates.

The most comprehensive tests on school bus idle emission rates known is from a thesis from Rowan University. Hearne (2003) was able to use the Aberdeen Test Center environmental chamber in Maryland to test school bus idle emissions of a range of temperatures (20-85F) and humidity values (40-90%). Three different buses were tested and the idle emission rates were, on average, 5,157 g/hr for CO_2, 112 g/hr for NO_x, 1.5 g/hr for $PM_{2.5}$, 34 g/hr for HC, and 81.99 g/hr for CO (Hearne, 2003). These results follow much more closely with the MOVES rates, especially for CO and HC. An examination of similar scope would be beneficial for the engine types in the CCSD buses, to obtain locally accurate idle emission rates. The comparison across all of the mentioned studies is shown in Table 5.10. As can be seen, there is a clear wide variation on the idle emission rates based on a number of factors mentioned previously and car should be taken when selecting the appropriate emission rate for savings reduction calculations and other policy and planning perspectives. After this analysis, the MOVES-produced rates still seem a bit high, but are within the 95% confidence intervals developed by Feng for NO_x and CO in HDDVs.

Table 5.10: Idle Emission Rates (Grams per Hour)

Idle Emission Rates in grams/hour from various studies									
Pollut-ant	MOVES	DEQ	Hearne 2003	Kinsey 2007	TTI Cycle Tests	TTI MOBILE6	Feng 2007 [d]	Feng 2007 [e]	EMFAC 2002 [ab]
NO_x	216.3	144.1	112.1	78.0	26.4	44.4	120.3	299.8	45.7-95.5
$PM_{2.5}$	4.2	3.9	1.5	0.34	-	-	-	-	0.072-4.76
HC	47.5	-	34.0	-	2.2	6.2	3.3	13.4	5.97-25.9
CO	85.1	-	81.9	31.8	4.4	37.5	21.4	102.3	16.6-28.4
CO_2	7,856-9,066 [c]	5,039	5,157	-	-	-	-	-	4,640

[a] vary by model year: older models have higher emission rates for all ranges except NO_x
[b] heavy duty diesel truck low-idle emission rates
[c] regular vs. extended idling (bins 1 and 200, respectively)
[d] mean emission rate - based on data from mostly transit buses
[e] high end of 95% confidence interval

CHAPTER 6

FUEL SAVINGS AND EMISSIONS REDUCTIONS

6.1 Fuel Savings Estimation

Estimated fuel savings were calculated by hand, using the current national diesel price of $3.95 per gallon (EIA, 2011). The number of gallons per hour consumed by school buses is generally considered to be 0.50 gallons per hour, as discussed in the project introduction (EPA, 2011). Given the average daily idle activity per bus, an annual fuel savings cost can quickly be calculated for the 480-vehicle instrumented fleet and Cobb County's full 1150 school bus fleet, using the following equation:

$$S = N * P * I_r * D * F$$

Where:

S = Annual Diesel Savings (gallons/year)

N = Number of buses in the fleet (bus)

P = Percent of buses in fleet that idle (%)

I_r = Average idle reduction per bus per operating day (hours/bus/day)

D = Number of operating days per year (days/year)

F = Rate of diesel consumption for an idling school bus (gallons/hour)

The average amount of idling reduced is defined in section 6.3.1. The number of operating days is taken as the number of school days in a year, which from the CCSD calendar was 180 days for the 2010-2011 school year. The annual savings in gallons is then multiplied by the cost per gallon of diesel, to calculate the annual savings in dollars.

6.2 Fuel Savings Results

Using the fuel savings equation explained in the methodology section, the expected annual fuel savings for the CCSD projects were tabulated. The results are shown in Table 6.1. Using the values collected from the analyzed idling data, CCSD can expect to save almost $68,000 per year with the installed fleet and nearly $162,000 per year if the entire fleet is installed with the components needed for the anti-idling system. These values assume the cost of diesel is $3.95 per gallon and that the rate of fuel consumption in idling buses is 0.50 gallons per hour (EPA, 2011), (EIA, 2011).

Table 6.1: Estimated Fuel Savings

	N	P (%)	I_r (min)	D	F (gal/hr)	S (gal)	Savings ($)
Project Fleet	480	80%	29.7	180	0.5	17,107	$ 67,573.44
CCSD Fleet	1150	80%	29.7	180	0.5	40,986	$ 161,894.70

Table 6.2 shows the estimated fuel efficiency improvement by limiting idling using the system. CCSD provided us with 2010 total VMT and fuel consumed by the entire fleet. Overall, the CCSD buses achieved 6.68 mpg, which could be improved 2.2% to 6.836 mpg after a year of implementation on the full fleet. The nearly 41,000 saved gallons is equivalent to reducing VMT by 275,000 miles. Dividing the dollar amount of fuel savings by the number of days results in the value of $908 wasted on fuel used during idling every day. With 80% of the 1150 buses idling (920), that’s $1 per bus per day wasted.

Table 6.2: Estimated Fuel Efficiency Improvements

	2010 Totals	Reduction	Future Est.	Percent Improvement
VMT (miles)	12,619,623		12,619,623	0%
Diesel Consumed (gal)	1,888,519	40,986	1,847,533	2%
Fuel Cost ($)	$7,459,650	$161,895	$ 7,297,755	2%
MPG	6.68		6.83	2%

6.3 Calculating Total Emissions

Total emissions were calculated using the emission rate lookup tables developed in MOVES and the operating mode bin total seconds distributions from the CCSD vehicle activity data. For example, the total seconds of activity in operation mode 12, coast/acceleration with STP between 0 and 3 and speed between 0 and 25 mph, was multiplied by the each pollutant's gram/second emission rate for operating mode 12 (from the RatePerDistance table). After calculating the total emissions for each operating mode, each pollutant was summed to obtain the total emission inventory for the study period.

The resulting emission inventory would be for the installed fleet over the course of the entire dataset defined earlier, the baseline emission rates. To obtain the total annual emissions for the project fleet of 480 buses and the CCSD fleet of 1150 buses, the total emissions have to be adjusted on a per-bus basis. The amount of activity in hours for one bus on one day spent in each bin is totaled across all trips, and then averaged across all buses. Because the operating characteristics are significantly different on school days and weekends, these days are separated and different averages are calculated. The resulting average activity per bin per bus per day is then multiplied by the number of buses in the analysis fleet, the number of days of each type (school day or non-school day), and the emission rate per hour to obtain the total annual fleet emission for a given pollutant. Idle emissions are calculated on a per second basis since no VMT is accrued while idling.

6.3.1 Emissions Savings from Idle Reduction

The potential maximum reduction is the total average daily amount of bus idling exceeding 120 seconds per event each day. However, eliminating the full amount of idling will be difficult to achieve. For the purposes of these analyses, the amount of idling expected includes all events longer than five minutes. To estimate reductions, all events with lengths longer than five minutes are flagged in the database and the average idle time per bus per day is quantified again without the extended idle events to estimate the average amount of idling that remains after strategy implementation.

To estimate the emission savings from the baseline emission rates that would be associated with elimination of excessive idling, the excess idle time can be removed from the activity in the idle operating mode bin (Bin 1) and recalculating emissions for that bin. Because no other activity bins will be affected, only the total emissions from Bin 1 need to be re-calculated. After Bin 1 emissions are reduced, the new emissions total is compared against the baseline scenario emissions to determine the savings. Similar processes could be used to adjust the emissions for various policy implementation tests, such as eliminating all school bus activity over a speed of 55 mph, but the project focus is to determine emission savings from idle reduction.

6.4 Total Emissions

6.4.1 Baseline Scenario Emissions

6.4.1.1 Using MOVES Rates

The emission totals shown in Table 6.3 are the total annual estimated emissions from the 480 bus project fleet, using the rates from MOVES. The amount of NO_x emissions is expected to be 197.3 tons per year, with 17%, or 33.7 tons, coming from idling alone. Approximately 6% of PM and CO_2 emissions come from idling, and as much as 55% of HC, and 36% of CO are from idling emissions. These high rates are explained by the fact that the emission rates are similar between idling and all other bins for HC and CO, and that idling is 38% of all activity. Each bus emits hundreds of pounds of pollutants per year, in addition to approximately 50 tons of CO_2.

Table 6.3: Baseline Emission Estimates from MOVES for 480-Bus Project Fleet

	480 Bus Fleet					
Pollutant	**NO_x**	**$PM_{2.5}$**	**PM_{10}**	**HC**	**CO**	**CO_2**
Total Emissions (tons)	197.3	11.8	11.4	13.5	36.9	24,009.2
Idling Emissions (tons)	33.7	0.7	0.6	7.4	13.3	1,414.3
% from Idling	17%	6%	6%	55%	36%	6%
Emissions Per Bus (tons)	0.41	0.02	0.02	0.03	0.08	50.02

Table 6.4 shows the annual emission estimates for the entire CCSD bus fleet. The emissions per bus and percentages from idling are the same as in the previous table. These rates are tied to constant factors that are weighted averages of the operating mode distribution and emission rate for each of those bins. The total amount emitted from the CCSD fleet per year is estimated to be 472 tons of NO_x, 28.2 tons of $PM_{2.5}$, 27.4 tons of PM_{10}, 32.2 tons of hydrocarbons, 88.5 tons of carbon monoxide, and 57,000 tons of CO_2.

A quick comparison to estimates for CO_2 emissions for the local transit agency, Metropolitan Atlanta Rapid Transit Authority (MARTA), shows that Cobb County school buses alone emit 41% of MARTA's 138,900 tons of CO_2 from the bus fleet (TravelMatters, 2002). Given that the VMT per bus is about 11,000 annual miles per year for CCSD, and 45,000 miles per year for MARTA, the fact that the CCSD buses emit over 41% of the local transit agency is significant. Estimates combining the Atlanta region's school bus fleets across ten counties would almost certainly show that school bus emissions greatly outweigh the amount from MARTA and other local transit agencies with much smaller fleets, and more attention should be paid to reducing the school bus fleets' emissions.

Table 6.4: Baseline Emission Estimates from MOVES for 1150-Bus CCSD Fleet

	1150 Bus Fleet					
Pollutant	**NO_x**	**$PM_{2.5}$**	**PM_{10}**	**HC**	**CO**	**CO_2**
Total Emissions (tons)	472.7	28.2	27.4	32.2	88.5	57,521.9
Idling Emissions (tons)	80.8	1.6	1.5	17.7	31.8	3,388.4
% from Idling	17%	6%	6%	55%	36%	6%
Emissions Per Bus (tons)	0.41	0.02	0.02	0.03	0.08	50.02

Figure 6.1 through 6.9 provide the total annual estimated emissions of each pollutant for the 1150 bus fleet by operating mode bin. Idling constitutes a significant portion of the emissions for every pollutant. Idling is the highest emitting operating mode bin for NO_x, HC, and CO. For PM, bin 30, which is high STP and $24 < v < 50$, leads the way with over 4.5 tons for both fine and coarse PM. Bin 16, which is low speed and high STP, is a close second with just over 2.5 tons. For CO_2, bin 16 leads with 9,000 tons, and bin 30 is a close second with over 7,500 annual emitted tons coming from that bin.

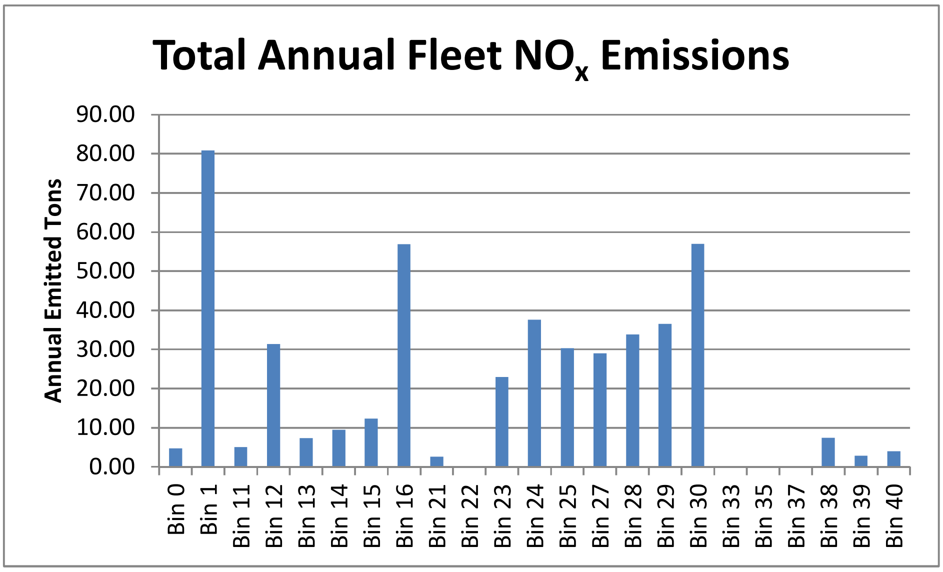

Figure 6.1: Total Annual Fleet NO_x Emissions

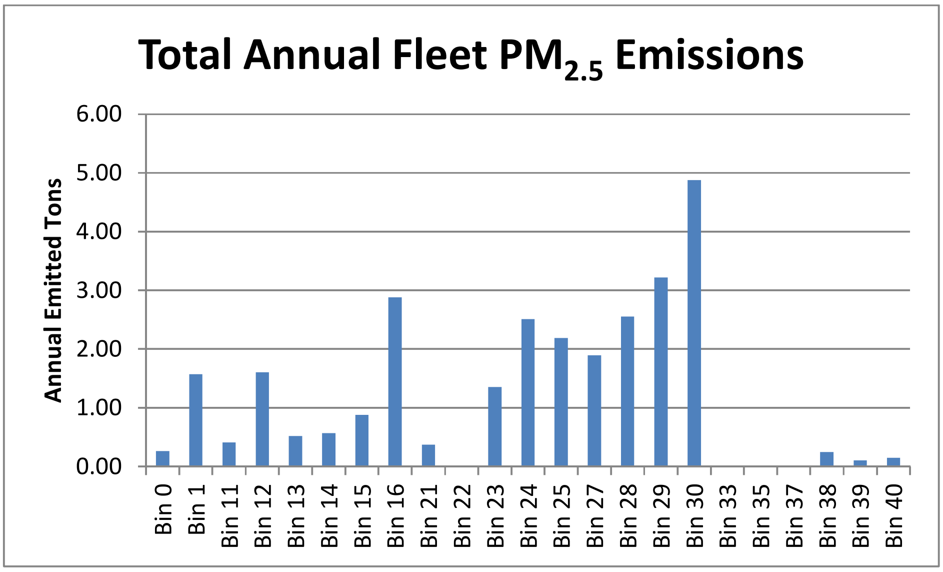

Figure 6.2: Total Annual Fleet $PM_{2.5}$ Emissions

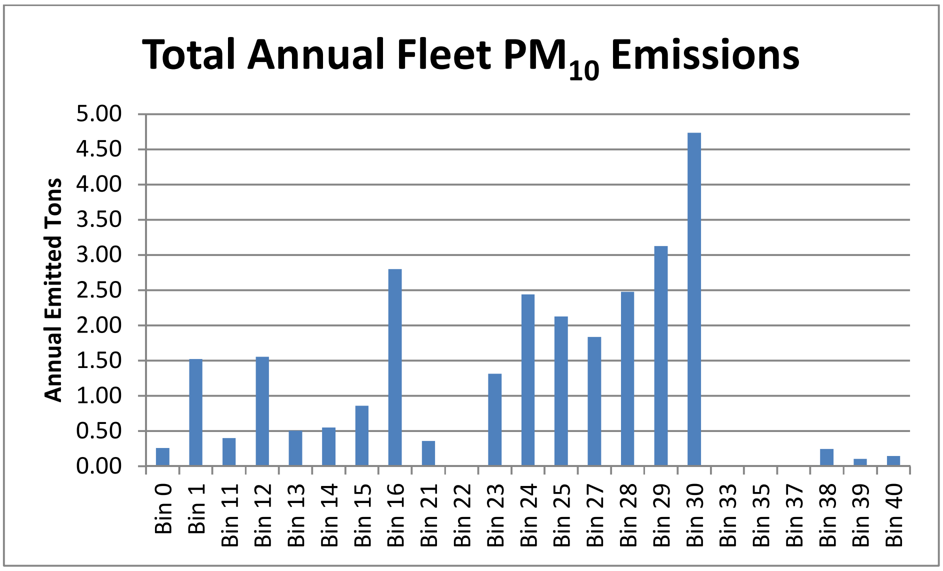

Figure 6.3: Total Annual Fleet PM_{10} Emissions

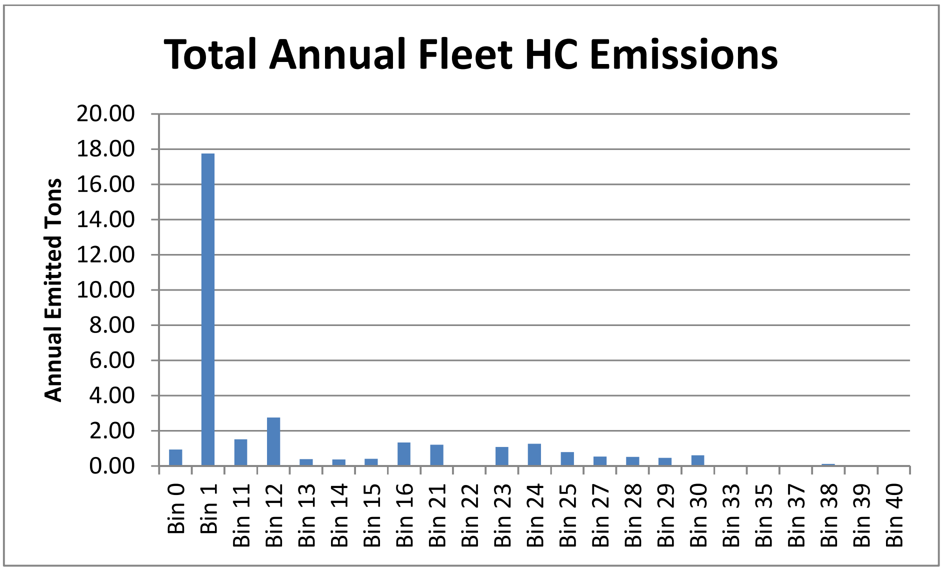

Figure 6.4: Total Annual Fleet HC Emissions

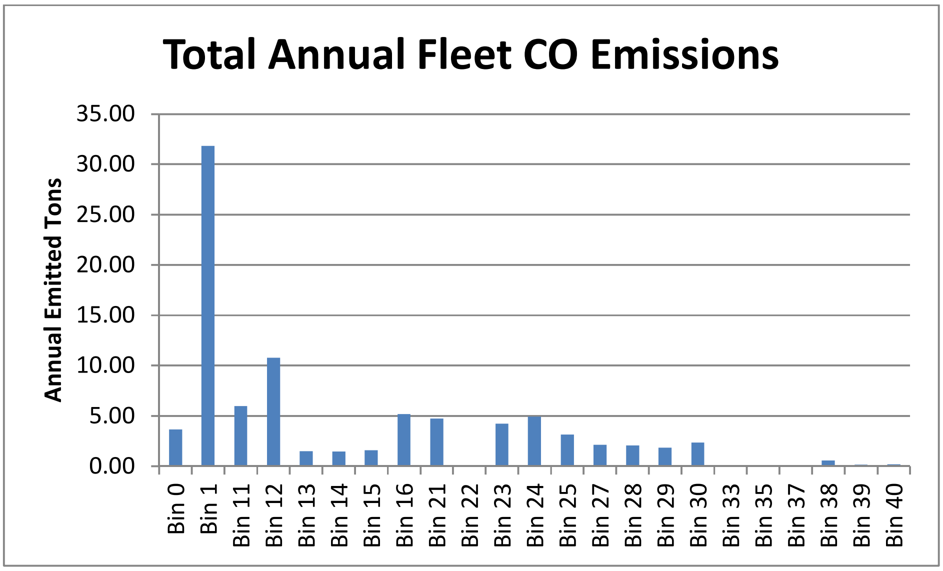

Figure 6.5: Total Annual Fleet CO Emissions

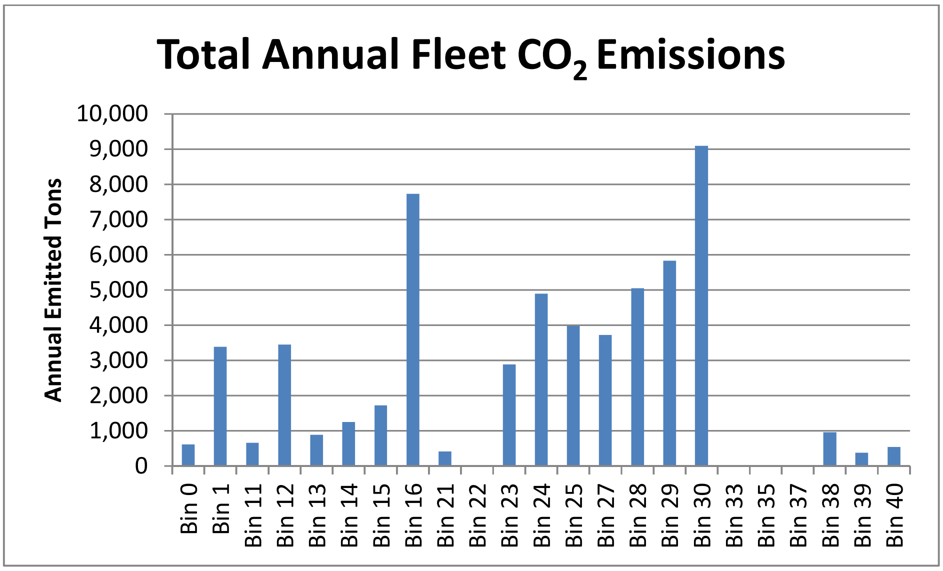

Figure 6.6: Total Annual Fleet CO_2 Emissions

6.4.1.2 Using DEQ Rates

The baseline annual emission totals using the DEQ for the 480 bus project fleet is shown in Table 6.5 below. The total CO_2 estimates are much lower because of the 80% lower rate used in DEQ. The DEQ shows a higher percentage of NO_x and PM coming from idling than does MOVES, even though the totals are lower. The prediction suggests that idling may be more important to the NO_x and PM rates than MOVES initially estimated. The DEQ estimates that only 73.1 tons of NO_x will be emitted annually, and only 1.4 tons of PM (98% of which is fine particulate matter), for the 480-bus project fleet. Only 0.003 tons (6 pounds) of PM is estimated to be emitted per bus over the course of the year. However, the DEQ may be underestimating these emissions given the operating characteristics and operating mode distribution of the observed CCSD fleet.

Table 6.5: Baseline Emission Estimates from DEQ for 480-bus Project Fleet

	480 Bus Fleet				
Pollutant	**NO_x**	**PM**	**HC**	**CO**	**CO_2**
Total Emissions (tons/yr)	73.1	1.4	4.1	10.7	8,749.6
Idling Emissions (tons/yr)	14.8	0.4	0.0	0.0	516.8
% from Idling	24%	34%	0%	0%	7%
Emissions Per Bus (tons/yr)	0.15	0.003	0.01	0.02	18.23

Table 6.6 shows the estimated total emissions of all CCSD buses using the Diesel Emission Quantifier. The emission estimates are again much less than the MOVES predicted emission totals. The total per-bus emissions remain constant. The total amount of NO_x emissions for the full CCSD fleet is estimated to be 175.2 tons, with 35.4 tons coming from idling. In either the MOVES or DEQ case, it is clear that significant savings on emissions can be achieved through idle-reduction strategies and controls.

Table 6.6: Baseline Emission Estimates from DEQ for 1150-bus CCSD Fleet

	1150 Bus Fleet				
Pollutant	**NO_x**	**PM**	**HC**	**CO**	**CO_2**
Total Emissions (tons)	175.2	3.3	9.8	25.6	20,962.6
Idling Emissions (tons)	35.4	1.0	0.0	0.0	1,238.2
% from Idling	20%	29%	0%	0%	6%
Emissions Per Bus (tons)	0.15	0.003	0.01	0.02	18.23

6.4.2 Emission Reduction Estimates from Program Implementation

The emission reduction estimates are based eliminating all idle events greater than five minutes in length. Using this elimination, the average amount of extended idling per bus per day is reduced from 29.7 minutes to 11.1 minutes per day on school days (a 63% reduction), and from 49.9 minutes to 5.89 minutes per day on weekends and holidays (an 88% reduction per bus day when vehicles idle on that day). The total yearly activity generated from this lower idling amount, and the savings were calculated and comparisons are drawn using MOVES and DEQ emission estimates as follows.

6.4.2.1 Using MOVES Estimates

Table 6.7 shows a summary of estimated emissions after idle reduction, on an annual basis. The total amount of NO_x is reduced from 197 tons to 167 tons, an 15% reduction. All of the emission reductions are based on the idle control strategies from the project. The project is expected to save 29.9 tons of NO_x per year, leaving just 3.8 tons per year due to idling. The estimated savings for fine particulate matter, is 0.6 tons, a 5% overall reduction, and an 89% reduction of idling emissions. The 89% reduction of idling emissions is constant across all pollutants, and is a function of the operating mode distribution of vehicle activity and the emission rate for each operating mode. The estimated 5% total savings of CO_2 emissions amounts over 1,200 tons per year. With idle controls implemented, the contribution of engine idle to total operating emissions should drop from 17% to 2% for NO_x, from 6% to 1% for PM, from 55% to 49% for HC, from 36% to 6% for CO, and from 6% to 1% for CO_2.

Table 6.7: Reduced Annual Emission Estimates from MOVES for 480-Bus Project Fleet

	480 Bus Fleet					
Pollutant	**NO_x**	**$PM_{2.5}$**	**PM_{10}**	**HC**	**CO**	**CO_2**
Total Emissions (tons)	167.4	11.2	10.9	6.9	25.1	22,755.1
% Reduction from Baseline	15%	5%	5%	49%	32%	5%
Idling Emissions (tons)	3.8	0.1	0.1	0.8	1.5	160.3
% Reduction from Baseline	89%	89%	89%	89%	89%	89%
% from Idling	2%	1%	1%	12%	6%	1%
% Reduction from Baseline	15%	5%	5%	43%	30%	5%
Emissions Per Bus (tons)	0.02	0.01	0.01	0.12	0.06	0.01
Emission Reduction (tons)	29.9	0.6	0.6	6.6	11.8	1,254.0

Applying the emission reductions to the entire CCSD fleet results in the emission savings estimates shown in Table 6.8. The largest savings can be seen in term of 71.7 tons of NO_x, nearly 1.4 ton of PM, 15.7 tons of HC, 28.2 tons of CO, and 3,000 tons of CO_2. Carbon monoxide from the fleet would be reduced from the baseline value of 88.5 tons to 60.2 tons, a 32% reduction, with 3.6 of the final CO tons from idling emissions. These estimates can be used to estimate the cost-effectiveness in terms of dollars per ton of pollutant for the purpose of implementing the idle control strategies and equipment on the remaining 670 buses without idle control equipment installed.

Table 6.8: Reduced Annual Emission Estimates from MOVES for 1150-Bus CCSD Fleet

	1150 Bus Fleet					
Pollutant	**NO_x**	**$PM_{2.5}$**	**PM_{10}**	**HC**	**CO**	**CO_2**
Total Emissions (tons)	401.0	26.8	26.0	16.5	60.2	54,517.5
% Reduction from Baseline	15%	5%	5%	49%	32%	5%
Idling Emissions (tons)	9.2	0.2	0.2	2.0	3.6	384.0
% Reduction from Baseline	89%	89%	89%	89%	89%	89%
% from Idling	2%	1%	1%	12%	6%	1%
% Reduction from Baseline	15%	5%	5%	43%	30%	5%
Emissions Per Bus (tons)	0.35	0.02	0.02	0.01	0.05	47.41
Emission Reduction (tons)	71.7	1.4	1.4	15.7	28.2	3,004.4

6.4.2.2 Using DEQ Estimates

The amount of savings reaped from DEQ emission estimates are lower than that of the MOVES results, again because of the lower emission rates used in DEQ. The emission reduction estimates shown here very closely follow those that were submitted with the original project grant application. The total estimated savings include: 12.2 tons of NO_x, 0.3 tons of PM, and 426 tons of CO_2. Idling emissions are all reduced 82% over baseline amounts. The total predicted emissions after idle reduction from the 480 bus project fleet is 60.9 tons of NO_x, 1.1 tons of PM, 4.1 tons of HC, 10.7 tons of CO, and 8,323 tons of CO_2. Emissions in reality vary over the course of the year, but since annual emission rates were developed using average annual temperatures and operating distributions, the annual results here can only be broken into equal monthly amounts.

Table 6.9: Reduced Annual Emission Estimates from DEQ for 480-Bus Project Fleet

	480 Bus Fleet				
Pollutant	**NO_x**	**PM**	**HC**	**CO**	**CO_2**
Total Emissions (tons)	60.9	1.1	4.1	10.7	8,323.3
% Reduction from Baseline	20%	31%	0%	0%	5%
Idling Emissions (tons)	2.6	0.1	0.0	0.0	90.6
% Reduction from Baseline	82%	82%			82%
% of Emissions from Idling	4%	7%	0%	0%	1%
% Reduction from Baseline	20%	27%			6%
Emissions Per Bus (tons)	0.13	0.002	0.01	0.02	17.34
Emission Reduction (tons)	**12.2**	**0.3**	**0.0**	**0.0**	**426.2**

The total estimated emissions from DEQ after the idle reduction are shown in Table 6.10 for the entire CCSD bus fleet. CO_2 can be reduced by over 1000 tons, NO_x can be reduced by 29 tons per year, and PM can be reduced by 0.8 tons based on these estimates. The NO_x reduction percentage reduction from the baseline emissions is 20%, while the PM reduction rate is 31%, and the CO_2 rate is 5%. It is clear from this table and the previous 3 tables that the majority of CO_2 emissions occur while burning the diesel during normal operation, and not during idling. NO_x and PM have particularly high emission rates during idling when compared to the running exhaust emission amounts for those pollutants.

Table 6.10: Reduced Emission Estimates from DEQ for 1150-Bus CCSD Fleet

	1150 Bus Fleet				
Pollutant	**NO_x**	**PM**	**HC**	**CO**	**CO_2**
Total Emissions (tons)	146.0	2.5	9.8	25.6	19,941.4
% Reduction from Baseline	20%	31%	0%	0%	5%
Idling Emissions (tons)	6.2	0.2	0.0	0.0	217.0
% Reduction from Baseline	82%	82%			82%
% of Emissions from Idling	4%	7%	0%	0%	1%
% Reduction from Baseline	16%	22%			5%
Emissions Per Bus (tons)	0.13	0.002	0.01	0.02	17.34
Emission Reduction (tons)	**29.2**	**0.8**	**0.0**	**0.0**	**1,021.2**

6.5 Health Benefits from Emission Reductions

DEQ includes estimations on the health benefits from fine particulate matter emission reductions. An estimated $1.3 million dollars per year can be saved from the reduction of PM emissions if the entire CCSD bus fleet is retrofitted with the idle-control equipment and strategies. This is based on the estimated change in $PM_{2.5}$ emissions and the impact on air quality for Cobb County. The health savings per year for just the 480-bus project fleet is $550,000. The methodology behind the health benefits estimator includes data from 2002 NEI data and the 2002 National Air Toxics Assessment (NATA) models, as well as the Environmental Benefits Mapping and Analysis Program (BenMAP) (NCDC, 2010). The health effects that are allocated a monetary value based on their avoidance are: premature mortality, chronic bronchitis, acute bronchitis, upper and lower respiratory problems, asthma exacerbation, nonfatal heart attacks, hospital admissions, emergency room visits, work loss days, and minor restricted-activity days. Each monetary benefit is backed by a supporting number of medical benefit quantification studies from 1987-2006.

The value of one ton of diesel PM reduction for Cob County is approximately $1.097 million per ton, compared to the national weighted average rate of $1.2 million dollars per ton. The lower benefit per ton ratio for Cobb County is expected due to the suburban and sprawling nature of the county despite its large population of nearly 700,000.

One limitation of the benefits calculator is that the results are presented on an annual basis. Ideally the benefits would be represented as an annualized process, but this would require an estimation of the benefits (and improvement in air quality, particularly PM) from implementation of the idle control strategy over the lifetime of the installed equipment and strategies. That is, emission reductions are variable over the long term and the health benefits that accumulate with those variable emission reductions are based on number of years of exposure at certain concentrations, such as 10 micrograms per cubic meter for PM (NCDC, 2010). Another key factor is that NO_x emissions also contribute to atmospheric formation of fine particulates, and have not been included in the $PM_{2.5}$ estimates in the DEQ model. The amount of health benefits therefore could potentially be greater. Because the model uses county-level population density estimates to determine what percentage of people are exposed to the additional emissions, local PM hot-spot analysis could show different benefit ratios for those living in a specific areas.

Children are expected to be especially susceptible to air pollution because of their high inhalation rates relative to body weight, their narrow lung airways, and immature immune systems (Marshall & Behrentz, 2005). Fitz, et al. found a concentration of 1 ppm of CO and 13 micrograms per cubic meter for $PM_{2.5}$ at bus loading and unloading zones. Concentrations at bus stops were even higher at 3 ppm for CO and 35 micrograms per cubic meter for $PM_{2.5}$. The self-pollution fraction of the bus during the commute increased these concentrations up to 56 ppm for $PM_{2.5}$ while in-route with windows closed (Fitz, Winer, & Colome, 2003). The 2006 EPA regulation for annual $PM_{2.5}$ pollution is 15 micrograms per cubic meter (EPA, 2011).

A significant amount of literature is available on the health impacts of emissions, especially from heavy-duty diesel vehicles, but they are not covered here, as the focus of the study was to analyze idling and quantify the emissions of the CCSD idle-reduction project. Significant detail is required for analyses of these types, given the nature of the human form and difficulty in quantifying in dollars the benefits of pollution reduction or health issues caused by high levels of pollution. The chief point is that reducing idling cuts emissions significantly, which has noteworthy secondary benefits such as health improvement for residents, especially sensitive groups such as children.

CHAPTER 7

CONCLUSIONS

7.1 School Bus Idling Characteristics

The research reported in this thesis found that school buses in the Cobb County fleet idle an average of about 64 minutes per day, with 30 of those minutes being extended idle, in the monitored period of January to May of 2011. The average amount of idling per bus per day is correlated with temperature with an R-square of about 0.5 in the winter and spring months; lower temperatures led to more idling. The opposite effect is expected for data collection in summer and fall: higher temperatures may lead to more idling for those paratransit buses with AC systems installed, to keep the cabin cool. Approximately 80% of all buses undertake idling for longer than two minutes on any given day, and each one logs on average 5.3 idle events per day. More idle events and more idle hours occur in the AM compared to the PM, due to the operation characteristics of CCSD and lower temperatures in the morning may have induced idling to provide additional heating of the bus interior.

Idling constitutes just over a third of total vehicle operation time. Buses idle per event longer in off-street and school zone locations, and shorter times at bus stops and intersections. Most of the bus's daily extended idle time, on average 18.5 minutes (62% of total idle) occurs at the school. A small subset of buses can be considered heavy idlers (those that idle more than 45 minutes per day), and these excessive events could be eliminated with proper education. Removing idle events longer than five minutes could result in an 88% reduction in idling. Idle was defined as being longer than 120 seconds, therefore more actual idling is occurring in the field than is reported in this thesis. Defining potential idle reduction at 90 seconds or less could lead to significantly greater reductions.

7.2 School Bus Emission Modeling

MOVES was used to develop emission rates based on operating mode distribution for even one average annual temperature (ignoring the variation of emission rates between months). Applying modal emission rates to second-by-second vehicle activity data resulted in emission estimates that are theoretically more accurate than other methods, but still limited by the default emission rates that are adjusted by local data in the MOVES model. The base rates strongly control all of the results. Additional emissions monitoring studies using portable emissions measurement devices at the tailpipe should be completed on school buses to increase the accuracy of emissions analysis. Based upon other studies, the MOVES emission rates developed appear to be comparable to data collected from in-use school buses, but may be higher than real-world emission rates.

The MOVES developed emission rates were multiplied by the VMT-adjusted vehicle activity operating hours in each operating mode bin to obtain the total emissions for two scenarios: the 480 bus project fleet over a full year and the 1150 bus CCSD fleet over an entire year. A more comprehensive method would vary temperature and humidity over the course of the year, and include information about road grade. All of the data could be input into MOVES for modeling work, but post-processing the emission rates for each operating bin, temperature, humidity, and road grade would be faster in terms of model run-time. Each additional variable added to MOVES to obtain more refined emission rates increases the number of MOVES runs by a factor of 23, so developing comparable external emission rate post-processing routines that match the internal mechanisms of MOVES may be more efficient than adding more input variables.

Using the DEQ to estimate emission savings that result from school bus control strategies will result in significantly lower emission reduction projections than are obtained from MOVES. The DEQ is much more efficient to use; however, it is important to determine through additional studies which model provides more accurate emission rates. If the DEQ significantly underestimates real-world emissions from school bus fleets, when comparative emission reduction and cost effectiveness analyses are performed in selecting projects for grant funding, school bus projects will be at a significant disadvantage for being selected. As such, future idle-control projects will be less likely to be selected even though they are very efficient and cost-effective means of providing emission reductions.

7.3 Project Effectiveness

The project implementing idle-reduction strategies deployed by Georgia Tech researchers and CCSD mechanics designed to limit school bus idling is expected to be extremely effective in reducing idling, saving fuel and money, and reducing emissions and mitigating the health impacts associated with idling. The telematics based hardware and software system developed represents a critical step in implementing cost-effective solutions to achieve environmental and financial goals for a large group of stakeholders, most notably CCSD, school children, parents, and local residents.

The study determined that on an annual basis, idling could be estimated to be reduced from about 30 minutes per bus per day to about 10 minutes per bus per day by implementation of a 5 minute maximum idling policy. The actual reductions produced will be analyzed in the fall.

Annual fuel savings estimates are on the order of 17,000 gallons for 480 buses, and 41,000 gallons for the whole fleet. At nearly $4 a gallon for the ULSD fuel, the savings for the whole fleet amount to over $160,000 dollars of savings in fuel per year, which alone is greater than the cost of implementation of the project over a five year period. The final benefit cost analysis will include the emission reductions and health savings associated with the project. The average fuel efficiency is increased slightly (2%) by eliminating unnecessary idling.

The emission reduction estimated through MOVES emission rates for the project fleet are 30 tons of NO_x, 1.2 tons of PM, 6.6 tons of gaseous hydrocarbons, 11.8 tons of CO, and over 1,250 tons of CO_2. Using the same idle reduction techniques on the entire CCSD fleet would result in even greater emissions reductions. A conservative estimate of the health benefits value of the $PM_{2.5}$ reduction is over half a million dollars per year.

7.4 Future Research

7.4.1 Emission Savings of Policy Implementations

Using the MOVES emission modeling methodology outlined in this study, a number of different policy applications can also be assessed. For example, given second-by-second vehicle activity data, the amount of vehicle activity in bins 33-40 (vehicle speed 50+ mph) can be quantified. Realistically, there is little need for school buses to travel more than 55 mph in the suburban setting of Cobb County. A policy could be developed by CCSD to monitor and eliminate all high-speed (55+ mph) or high-load operations. The vehicle activity in this category can easily be quantified through the second-by-second data, and emission savings can be quantified.

The process would be to replace all activity above 55 mph with activity at 55 mph, and determine the difference in emissions. Estimated policy compliance factors should be applied to determine the amount of emissions, or idling, or high-speed operation reduced, because all bus drivers will not likely comply 100% of the time with an operating policy. However, compliance is expected to be higher with the use of a real-time tracking system, because dispatches can easily notify and warn drivers that cross the threshold of the policy, in this case: speeding over 55 mph.

7.4.2 Engine Shut-off Idle Reduction Verification

One of the next steps in the project is to verify the estimates developed for idle reduction. In the coming months, nearly all buses will have been installed with the idle-detection circuits, so that bus drivers are being tracked and will be notified of their excess idling status by the CCSD bus dispatchers. The vehicle activity records after the system is fully functional will reflect any changes in idling that were made before and after the installation and driver warning system was implemented. The estimate of idle reduction made in this study was the elimination of all idle events longer than five minutes. Additionally, a similar analysis will be performed after the engine shut-off circuits are installed, to determine if additional idle reductions are accrued due to warning+shut-off rather than just the warning system. With effective dispatcher notification, the marginal benefit of additional shut-off control may not significantly reduce emissions much further than the idle warning system; driver notification via dispatchers may be enough. Most bus drivers understand the implications of idling and will be given additional training before the engine shut-off phase of the project begins.

7.4.3 Engine Shut-off Emissions Reduction Verification

Unfortunately, under the ARRA funding program, no funds can be dedicated to emission testing to verify emission reductions. Portable emission monitoring systems could be installed on the tailpipes of a number of the CCSD buses to quantify the actual pollutant emission rates. Linking the emission data with the vehicle activity data would better determine the actual emission rates of each operating mode. The linkage of this data would result in improved emission estimates, especially idling emission rates. The analysis of emission reduction and savings could be reapplied using the new field-collected emission rates rather than estimates calculated through MOVES, and true project cost-effectiveness could be calculated. The MOVES model accuracy (and other models, such as DEQ and HDDV-MEM) could also be compared to determine whether the range of assumptions and model parameters accurately predict the emission for the analysis fleet.

7.4.4 Determination of Allowable Idle Time

To increase the accuracy of the length of idling for each location type mentioned in section 4.2.4, more work can be done to using GIS to determine the distribution of idling lengths. A small scale analysis was performed in this study, but that was after the idle events had already been filtered by a minimum 120 second length. To determine the full distribution at each location, all idling events (even as short as one second) could be considered. It is very likely that the average length of a bus stop is less than 120 seconds, so the analysis performed before was only looking at the distribution for a subset of bus stops (the longer than average subset). The categorization process using GIS would be the same as before, using different geo-fencing and proximity functions with a hierarchy of place to determine the categorical location of idling. After categorizing the idling events into bus stop, intersection, school area, out-of-network, on-street, and off-street idling events, each subset of data could be analyzed to determine the characteristics of idling and waiting at that specific location.

Including the additional idle that may have been missed in this analysis or excluding additional idle that should not have been included (allowable idle) will not change the emission rates developed in MOVES, but the total idle activity and therefore emissions could increase based on the proposed methodologies outlined below.

7.4.4.1 Bus Stops

Using the latitude and longitude coordinates from the GPS units and the idle state reported to the server in combination with geocoded bus stops provided by CCSD, the average length of idling (average bus stop time) can be determined for the entire installed fleet. Additionally, averages could be established for each individual school or each bus route to accommodate longer loading times for handicapped students. At a school bus stop, the 95^{th} percentile of the bus stop length in seconds could be used to classify idling events, whether that is 60 seconds, 90 seconds, or another value. Given the new bus-stop specific allowable idling time, any idling above this established amount would go into the idle event repository. Dispatchers could then warn the drivers of the excessive idling occurring at a certain bus stop. Determining when buses do *not* idle at an intersection would require further GIS analysis. Refining the allowable idle time at bus stops from the 120 seconds used in this study could increase the amount of idling reduced, as well as providing a more accurate assessment of allowable idle times for bus stops. Similar processing could be performed for various special (allowable) idling events and locations.

7.4.4.2 Other Allowed Idling Locations

Other locations where refining the allowable idle time might be appropriate include: bus maintenance yards, intersections, and school bus loading/unloading areas and parking lots. Intersections would likely have the greatest variation in idling time, as predicting the length of queues in seconds at each intersection in Cobb County at certain times of the day would be difficult. The time a bus spends waiting at an intersection is a function of numerous different variables such as: time of day, traffic congestion level in the area, the phase during which the bus arrives, the length of that phase, the signal characteristics (pre-timed, actuated, coordinated, etc.), pedestrians, and geometric or physical constraints. After finding the distribution of idling (queuing) times for school buses near intersections, the 95^{th} percentile could again be used as the acceptable idle time, with events exceeding that length classifying as an unnecessary idle event. Whereas unnecessary idling at schools can be directly controlled by the driver, extended idling at intersections cannot. The school district can assemble the delay information and use the data to lobby for changes in signal timing operations at the intersections in question to reduce the idle and delay experienced by the buses.

School loading and unloading areas can be analyzed in a similar way to bus stops, but the results would be limited to information purposes only, as there is no need to have the bus running while students get on or off the bus. School areas should have a very low allowable idling time. The treatment for bus maintenance yards would be contingent upon what maintenance was needed on each bus and if that type of maintenance required the engine to be on or not.

7.4.5 Matching Vehicle Activity Record to Road Network

To quantify the impacts of road grade and further increase the accuracy of engine load power calculations, and therefore emissions for the MOVES modeling framework, the vehicle activity should be matched to road network information. Each second of vehicle activity data would be matched by latitude and longitude coordinates reported by GPS to positions along the road link and the associated road grade. The location of the link and the grade at that location could provide more detailed information about the characteristics of engine power on the second-by-second basis. The matched road network activity information could also be used directly by the HDDV-MEM method mentioned previously for potentially higher-accuracy emission calculations.

7.4.6 Further Idle Analyses

Because our study period consisted of only three months in the spring, the resulting average values as discussed in Chapter 4 are limited in their applicability. These average idle values might not apply to summer, fall or winter. The idling amounts are also specific to Cobb County, Georgia. A number of factors such as weather, climate, local or state idling policies could greatly influence the amount of idling per bus. To implement a similar project in other municipalities with large bus fleets or a large air-quality-sensitive population, it is recommended that local sample data be collected to assess the cost-effectiveness of a given project. The local values can be estimated by following the same modeling methodology outlined in this thesis. For example, the annual average idle amount determined in a study in Oklahoma was 23.7 minutes, but varied across all months of the year (Anderson & Glencross, 2009). Depending on the size of a bus fleet and local fuel price, the difference between 30.1 minutes as found in this study for the spring months of March, April, and May and 23.7 minutes can make a significant difference in terms of fuel savings.

Individual bus routes, schools, and regions within a county may undertake differing amounts of idling. For example the culture and idea of idling could vary by school due to parent or teacher influence. Some groups of bus drivers may consider idling to be serious, and others may not think it is a big deal. Geographical features by region of a county, such as a valley where weather can be significantly different than other areas of a county, could affect the average idle time per bus in that region. Route-specific idle variation is most likely directly related to driver behavior, but over a longer course of time, after driver changes, certain bus routes may have more idling due to specific nature of the route, such as limited places to park and shut off the bus at the beginning or end of the route.

With bus-specific information from the CCSD FuelMaster records, an average mile-per-gallon diesel consumption rate could be determined as a before-and-after study for the implementation of the different phases of the project. The mileage and diesel consumption per bus is readily available and archived up to at least a year in their database. An example analysis of the annual average fuel economy improvement was performed in the Oklahoma school bus idling study (Anderson & Glencross, 2009). An additional improvement that could be made on this study is to re-process the trip files so that any activity that is within an extended idle event is included in the idling total, even though the instantaneous speed may have jumped out of the -1 to 1 mph speed range due to GPS wander. This effect was estimated to be a very small percentage of the dataset considered.

This thesis has presented a methodology for modeling the potential emission reductions from the implementation of an anti-idle program, as well as an analysis of school bus idling activity for a large school district in the Atlanta metro area. Coupling grams/second operating mode emission rates from the EPA MOVES model with second-by-second vehicle activity allows researchers to prepare more refined estimates of bus emissions under real-world operating conditions. Using the patent-pending circuit to detect whether the bus engine is on and whether the bus is stationary, greatly improves the accuracy of idle estimation and consequently, emission reduction estimates for the idle control program currently being implemented. The projected emission reduction from the extended idle notification and automatic shutoff system should be very significant, an estimated 15% reduction in emissions of NO_x, 5% reduction in PM, 49% reduction HC, 32% reduction in CO, 5% reduction in CO_2, and saving an estimated 17,000 gallons in fuel. The system even has the potential to pay for itself through the reduction in fuel consumption, amounting to an estimated $67,000. The reduction of diesel particulate matter emissions in and around school zones will positively impact the health of school children, parents, teachers, and bus drivers. The idle control methodology currently being implemented constitutes an innovative and cost-effective solution that is implementable using today's technologies. The potential for expanding the use of idle control technologies in other regions is significant.

APPENDIX A: AVERAGE DAILY IDLE TIMES BY BUS

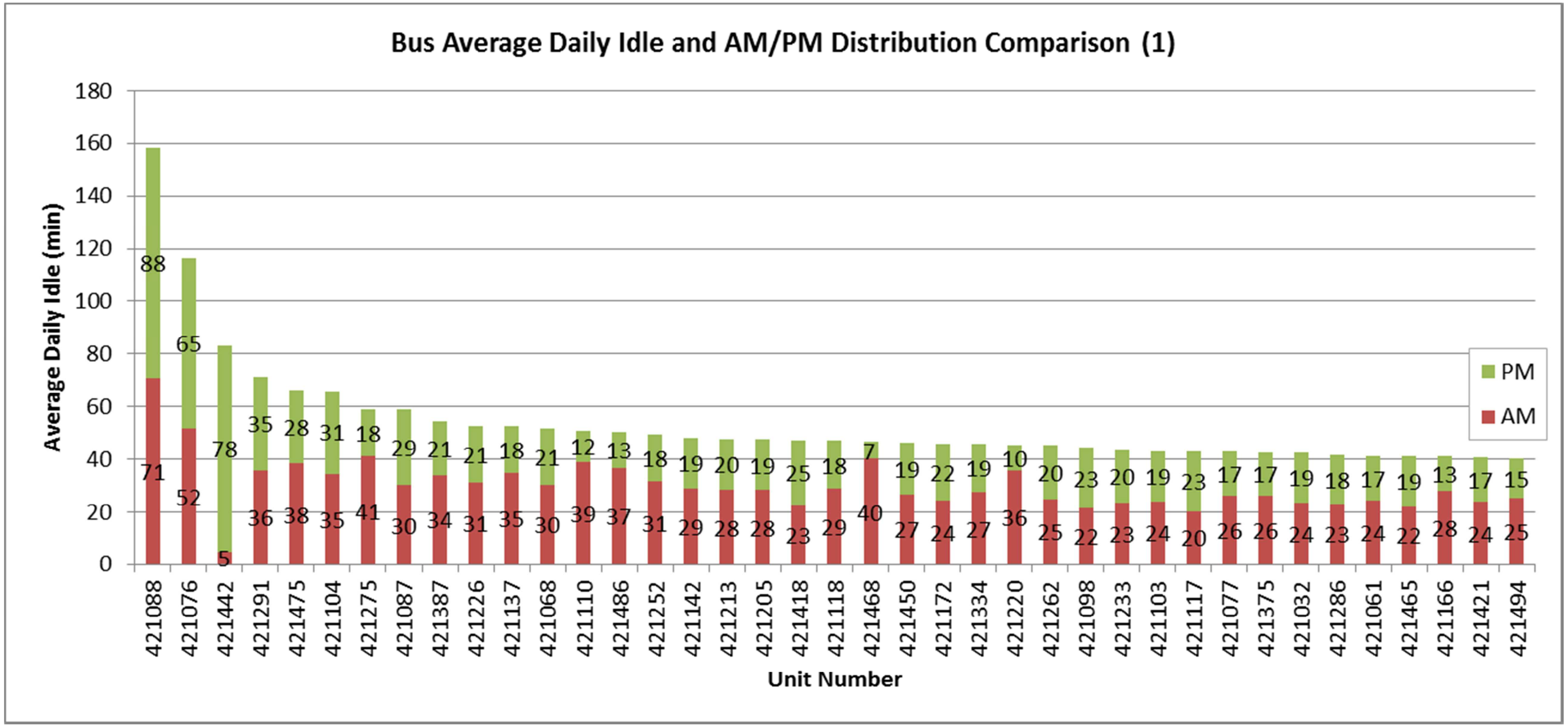

Figure A.1: Distribution of Average AM/PM Daily Idle By Bus (1)

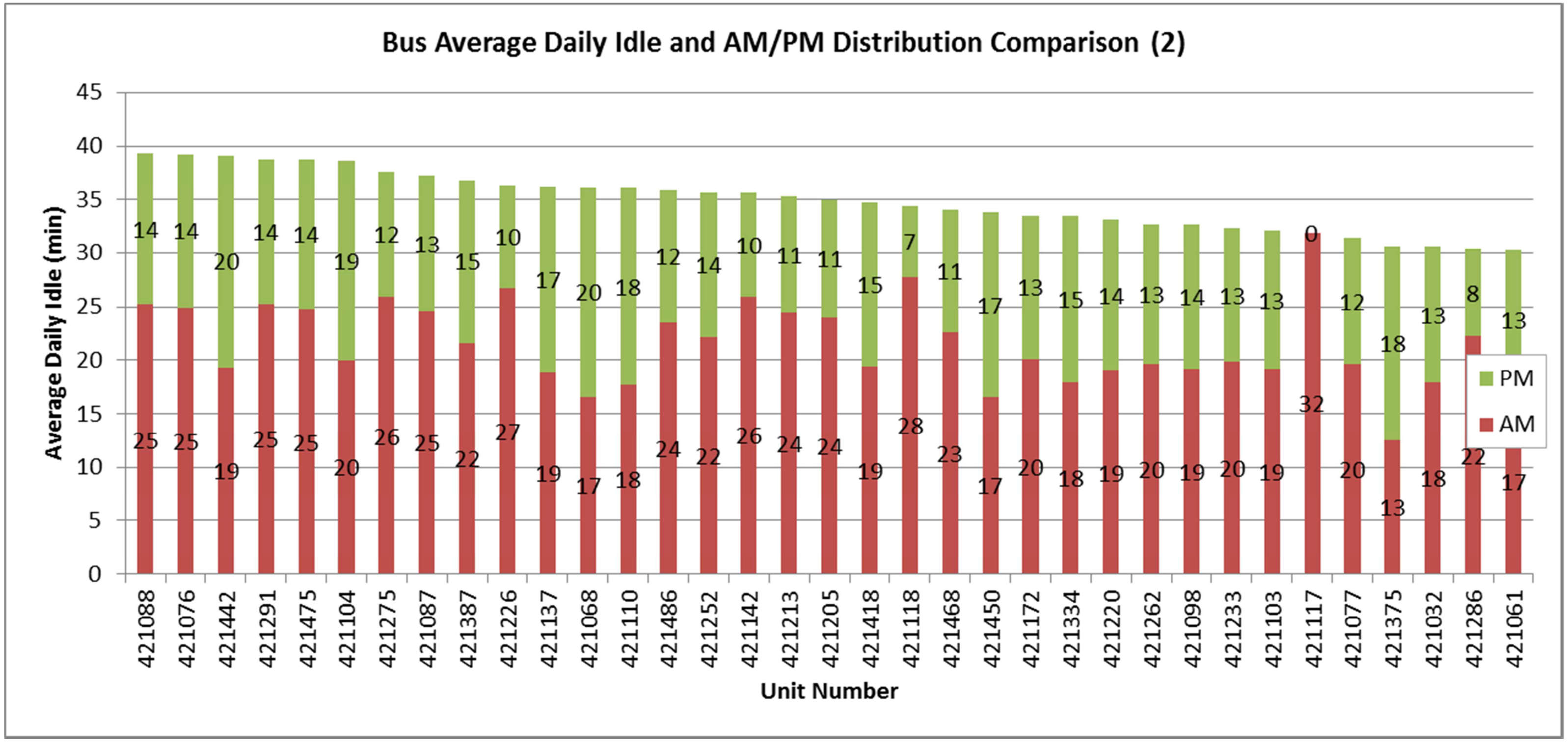

Figure A.2: Distribution of Average AM/PM Daily Idle By Bus (2)

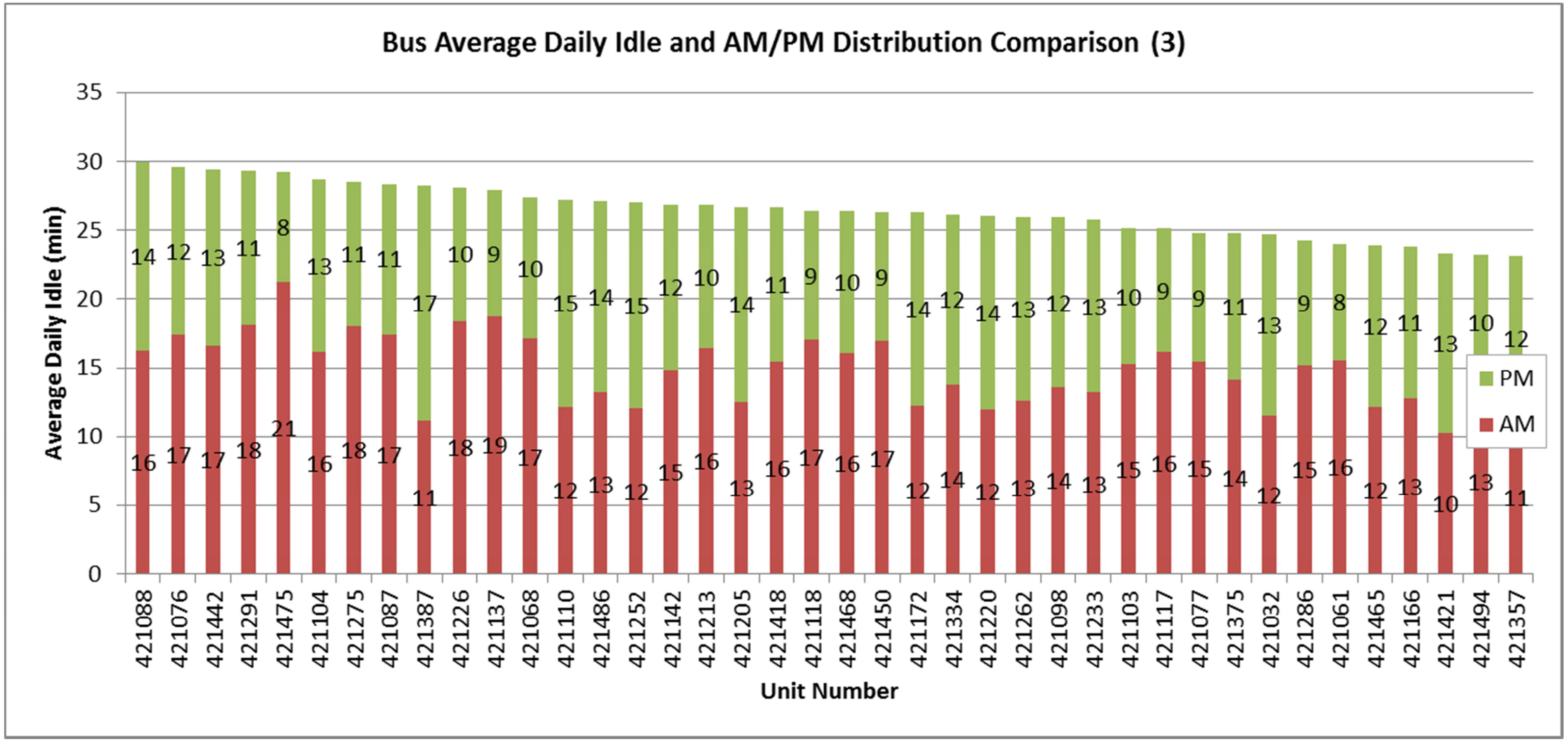

Figure A.3: Distribution of Average AM/PM Daily Idle By Bus (3)

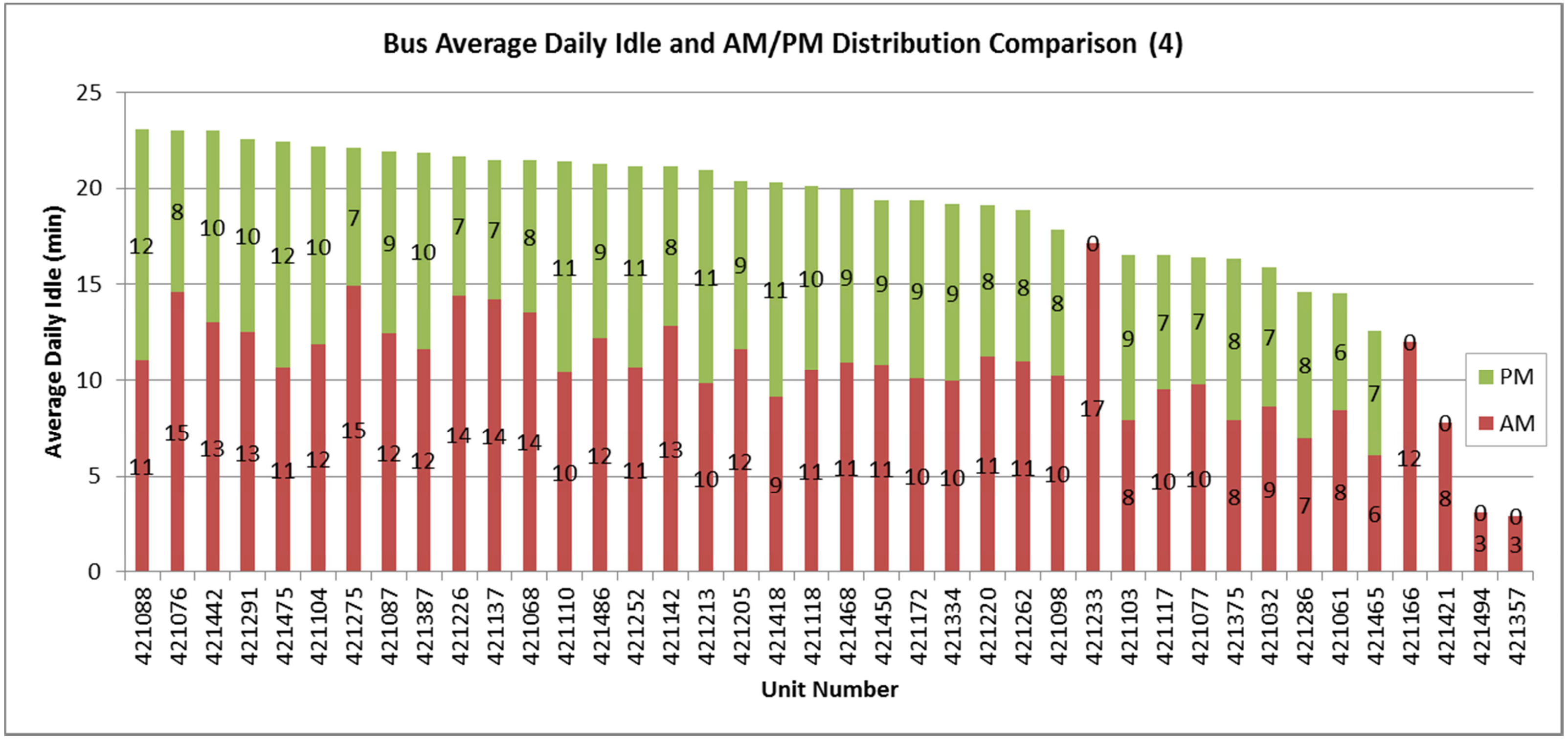

Figure A.4: Distribution of Average AM/PM Daily Idle By Bus (4)

APPENDIX B: MOVES DECODER

MOVES "Decoder"

SourceType	
sourcetypeid	**sourcetypename**
11	Motorcycle
21	Passenger Car
31	Passenger Truck
32	Light Commercial Truck
41	Intercity Bus
42	Transit Bus
43	School Bus
51	Refuse Truck
52	Single Unit Short-haul Truck
53	Single Unit Long-haul Truck
54	Motor Home
61	Combination Short-haul Truck
62	Combination Long-haul Truck

Process	
processid	**processName**
1	Running Exhaust
2	Start Exhaust
9	Brakewear
10	Tirewear
11	Evap Permeation
12	Evap Fuel Vapor Venting
13	Evap Fuel Leaks
15	Crankcase Running Exhaust
16	Crankcase Start Exhaust
17	Crankcase Extended Idle Exhaust
18	Refueling Displacement Vapor Loss
19	Refueling Spillage Loss
90	Extended Idle Exhaust

Pollutant	
pollutantid	**pollutantname**
1	Total Gaseous Hydrocarbons
2	Carbon Monoxide (CO)
3	Oxides of Nitrogen
5	Methane (CH4)
6	Nitrous Oxide (N2O)
20	Benzene
21	Ethanol
22	MTBE
23	Naphthalene
24	1,3-Butadiene
25	Formaldehyde
26	Acetaldehyde
27	Acrolein
30	Ammonia (NH3)
31	Sulfur Dioxide (SO2)
32	Nitrogen Oxide
33	Nitrogen Dioxide
79	Non-Methane Hydrocarbons
80	Non-Methane Organic Gases
86	Total Organic Gases
87	Volatile Organic Compounds
90	Atmospheric CO2
91	Total Energy Consumption
92	Petroleum Energy Consumption
93	Fossil Fuel Energy Consumption
98	CO2 Equivalent
100	Primary Exhaust PM10 - Total
101	Primary PM10 - Organic Carbon
102	Primary PM10 - Elemental Carbon
105	Primary PM10 - Sulfate Particulate
106	Primary PM10 - Brakewear Particulate
107	Primary PM10 - Tirewear Particulate
110	Primary Exhaust PM2.5 - Total
111	Primary PM2.5 - Organic Carbon
112	Primary PM2.5 - Elemental Carbon
115	Primary PM2.5 - Sulfate Particulate
116	Primary PM2.5 - Brakewear Particulate
117	Primary PM2.5 - Tirewear Particulate

Day	
dayID	**dayName**
2	Weekend
5	Weekdays

Road Type	
roadtypeid	**roaddesc**
1	Off-Network
2	Rural Restricted Access
3	Rural Unrestricted Access
4	Urban Restricted Access
5	Urban Unrestricted Access

FuelType	
fuelTypeID	**fuelTypeDesc**
1	Gasoline
2	Diesel Fuel
3	Compressed Natural Gas
9	Electricity

Activity		
activityTypeID	**activityType**	**activityTypeDesc**
1	distance	Distance traveled
2	sourcehours	Source Hours
3	extidle	Extended Idle Hours
4	sho	Source Hours Operating
5	shp	Source Hours Parked
6	population	Population
7	starts	Starts

SCCV Type		
SCCVtypeID	**PART5SCCV typeDesc**	**MOBILE6SCCVtypeDesc**
1	LDGV	1, 'LDGV', 'Light Duty Gasoline Vehicles (LDGV)'
2	LDGT1	Light Duty Gasoline Trucks 1 & 2
3	LDGT2	Light Duty Gasoline Trucks 3 and 4
4	HDGV	Heavy Duty Gasoline Vehicles 2B thru 8B and Gasoline Buses
5	MC	Motorcycles (MC)
6	LDDV	Light Duty Diesel Vehicles (LDDV)
7	LDDT	Light Duty Diesel Trucks 1 thru 4 (LDDT)
8	2BHDDV	Heavy Duty Diesel Vehicles (HDDV) Class 2B
9	LHDDV	Heavy Duty Diesel Vehicles (HDDV) Class 3, 4, and 5
10	MHDDV	Heavy Duty Diesel Vehicles (HDDV) Class 6 and 7
11	HHDDV	Heavy Duty Diesel Vehicles (HDDV) Class 8A and 8B
12	BUSES	Heavy Duty Diesel Buses (School and Transit)

Figure B.1: MOVES Decoder

APPENDIX C: EMISSION RATE LOOKUP TABLES

Table C.1: Running Emission Rates for All Pollutant Processes by Operating Mode

pollutantID	Pollutant Name	processID	Process Name	MOVESScenarioID	Emssion Rate (grams/hour)
1	Total Gaseous Hydrocarbons	1	Running Exhaust	Bin21	17.63
1	Total Gaseous Hydrocarbons	1	Running Exhaust	Bin22	17.63
1	Total Gaseous Hydrocarbons	1	Running Exhaust	Bin23	17.63
1	Total Gaseous Hydrocarbons	1	Running Exhaust	Bin24	17.63
1	Total Gaseous Hydrocarbons	1	Running Exhaust	Bin25	17.63
1	Total Gaseous Hydrocarbons	1	Running Exhaust	Bin27	17.63
1	Total Gaseous Hydrocarbons	1	Running Exhaust	Bin28	17.63
1	Total Gaseous Hydrocarbons	1	Running Exhaust	Bin29	17.63
1	Total Gaseous Hydrocarbons	1	Running Exhaust	Bin30	17.63
1	Total Gaseous Hydrocarbons	1	Running Exhaust	Bin33	31.49
1	Total Gaseous Hydrocarbons	1	Running Exhaust	Bin35	31.49
1	Total Gaseous Hydrocarbons	1	Running Exhaust	Bin37	31.49
1	Total Gaseous Hydrocarbons	1	Running Exhaust	Bin38	31.49
1	Total Gaseous Hydrocarbons	1	Running Exhaust	Bin39	31.49
1	Total Gaseous Hydrocarbons	1	Running Exhaust	Bin40	31.49
1	Total Gaseous Hydrocarbons	15	Crankcase Running Exhaust	Bin21	0.35
1	Total Gaseous Hydrocarbons	15	Crankcase Running Exhaust	Bin22	0.35
1	Total Gaseous Hydrocarbons	15	Crankcase Running Exhaust	Bin23	0.35
1	Total Gaseous Hydrocarbons	15	Crankcase Running Exhaust	Bin24	0.35
1	Total Gaseous Hydrocarbons	15	Crankcase Running Exhaust	Bin25	0.35
1	Total Gaseous Hydrocarbons	15	Crankcase Running Exhaust	Bin27	0.35
1	Total Gaseous Hydrocarbons	15	Crankcase Running Exhaust	Bin28	0.35
1	Total Gaseous Hydrocarbons	15	Crankcase Running Exhaust	Bin29	0.35
1	Total Gaseous Hydrocarbons	15	Crankcase Running Exhaust	Bin30	0.35
1	Total Gaseous Hydrocarbons	15	Crankcase Running Exhaust	Bin33	0.63
1	Total Gaseous Hydrocarbons	15	Crankcase Running Exhaust	Bin35	0.63
1	Total Gaseous Hydrocarbons	15	Crankcase Running Exhaust	Bin37	0.63
1	Total Gaseous Hydrocarbons	15	Crankcase Running Exhaust	Bin38	0.63
1	Total Gaseous Hydrocarbons	15	Crankcase Running Exhaust	Bin39	0.63
1	Total Gaseous Hydrocarbons	15	Crankcase Running Exhaust	Bin40	0.63

pollutantID	Pollutant Name	processID	Process Name	MOVESScenarioID	Emssion Rate (grams/hour)
2	Carbon Monoxide (CO)	1	Running Exhaust	Bin21	69.93
2	Carbon Monoxide (CO)	1	Running Exhaust	Bin22	69.93
2	Carbon Monoxide (CO)	1	Running Exhaust	Bin23	69.93
2	Carbon Monoxide (CO)	1	Running Exhaust	Bin24	69.93
2	Carbon Monoxide (CO)	1	Running Exhaust	Bin25	69.93
2	Carbon Monoxide (CO)	1	Running Exhaust	Bin27	69.93
2	Carbon Monoxide (CO)	1	Running Exhaust	Bin28	69.93
2	Carbon Monoxide (CO)	1	Running Exhaust	Bin29	69.93
2	Carbon Monoxide (CO)	1	Running Exhaust	Bin30	69.93
2	Carbon Monoxide (CO)	1	Running Exhaust	Bin33	136.00
2	Carbon Monoxide (CO)	1	Running Exhaust	Bin35	136.00
2	Carbon Monoxide (CO)	1	Running Exhaust	Bin37	136.00
2	Carbon Monoxide (CO)	1	Running Exhaust	Bin38	136.00
2	Carbon Monoxide (CO)	1	Running Exhaust	Bin39	136.00
2	Carbon Monoxide (CO)	1	Running Exhaust	Bin40	136.00
2	Carbon Monoxide (CO)	15	Crankcase Running Exhaust	Bin21	0.21
2	Carbon Monoxide (CO)	15	Crankcase Running Exhaust	Bin22	0.21
2	Carbon Monoxide (CO)	15	Crankcase Running Exhaust	Bin23	0.21
2	Carbon Monoxide (CO)	15	Crankcase Running Exhaust	Bin24	0.21
2	Carbon Monoxide (CO)	15	Crankcase Running Exhaust	Bin25	0.21
2	Carbon Monoxide (CO)	15	Crankcase Running Exhaust	Bin27	0.21
2	Carbon Monoxide (CO)	15	Crankcase Running Exhaust	Bin28	0.21
2	Carbon Monoxide (CO)	15	Crankcase Running Exhaust	Bin29	0.21
2	Carbon Monoxide (CO)	15	Crankcase Running Exhaust	Bin30	0.21
2	Carbon Monoxide (CO)	15	Crankcase Running Exhaust	Bin33	0.41
2	Carbon Monoxide (CO)	15	Crankcase Running Exhaust	Bin35	0.41
2	Carbon Monoxide (CO)	15	Crankcase Running Exhaust	Bin37	0.41
2	Carbon Monoxide (CO)	15	Crankcase Running Exhaust	Bin38	0.41
2	Carbon Monoxide (CO)	15	Crankcase Running Exhaust	Bin39	0.41
2	Carbon Monoxide (CO)	15	Crankcase Running Exhaust	Bin40	0.41
3	Oxides of Nitrogen (NOx)	1	Running Exhaust	Bin0	123.72
3	Oxides of Nitrogen (NOx)	1	Running Exhaust	Bin1	98.39
3	Oxides of Nitrogen (NOx)	1	Running Exhaust	Bin11	79.94
3	Oxides of Nitrogen (NOx)	1	Running Exhaust	Bin12	278.74
3	Oxides of Nitrogen (NOx)	1	Running Exhaust	Bin13	466.68
3	Oxides of Nitrogen (NOx)	1	Running Exhaust	Bin14	622.77

pollutantID	Pollutant Name	processID	Process Name	MOVESScenarioID	Emssion Rate (grams/hour)
3	Oxides of Nitrogen (NOx)	1	Running Exhaust	Bin15	742.24
3	Oxides of Nitrogen (NOx)	1	Running Exhaust	Bin16	1049.11
3	Oxides of Nitrogen (NOx)	1	Running Exhaust	Bin21	37.76
3	Oxides of Nitrogen (NOx)	1	Running Exhaust	Bin22	235.12
3	Oxides of Nitrogen (NOx)	1	Running Exhaust	Bin23	381.86
3	Oxides of Nitrogen (NOx)	1	Running Exhaust	Bin24	533.65
3	Oxides of Nitrogen (NOx)	1	Running Exhaust	Bin25	682.19
3	Oxides of Nitrogen (NOx)	1	Running Exhaust	Bin27	956.55
3	Oxides of Nitrogen (NOx)	1	Running Exhaust	Bin28	1155.64
3	Oxides of Nitrogen (NOx)	1	Running Exhaust	Bin29	1390.60
3	Oxides of Nitrogen (NOx)	1	Running Exhaust	Bin30	1699.63
3	Oxides of Nitrogen (NOx)	1	Running Exhaust	Bin33	263.07
3	Oxides of Nitrogen (NOx)	1	Running Exhaust	Bin35	961.54
3	Oxides of Nitrogen (NOx)	1	Running Exhaust	Bin37	1485.82
3	Oxides of Nitrogen (NOx)	1	Running Exhaust	Bin38	1823.29
3	Oxides of Nitrogen (NOx)	1	Running Exhaust	Bin39	2228.89
3	Oxides of Nitrogen (NOx)	1	Running Exhaust	Bin40	2724.19
3	Oxides of Nitrogen (NOx)	15	Crankcase Running Exhaust	Bin0	0.06
3	Oxides of Nitrogen (NOx)	15	Crankcase Running Exhaust	Bin1	0.05
3	Oxides of Nitrogen (NOx)	15	Crankcase Running Exhaust	Bin11	0.04
3	Oxides of Nitrogen (NOx)	15	Crankcase Running Exhaust	Bin12	0.14
3	Oxides of Nitrogen (NOx)	15	Crankcase Running Exhaust	Bin13	0.23
3	Oxides of Nitrogen (NOx)	15	Crankcase Running Exhaust	Bin14	0.31
3	Oxides of Nitrogen (NOx)	15	Crankcase Running Exhaust	Bin15	0.37
3	Oxides of Nitrogen (NOx)	15	Crankcase Running Exhaust	Bin16	0.52
3	Oxides of Nitrogen (NOx)	15	Crankcase Running Exhaust	Bin21	0.02
3	Oxides of Nitrogen (NOx)	15	Crankcase Running Exhaust	Bin22	0.12
3	Oxides of Nitrogen (NOx)	15	Crankcase Running Exhaust	Bin23	0.19
3	Oxides of Nitrogen (NOx)	15	Crankcase Running Exhaust	Bin24	0.27
3	Oxides of Nitrogen (NOx)	15	Crankcase Running Exhaust	Bin25	0.34
3	Oxides of Nitrogen (NOx)	15	Crankcase Running Exhaust	Bin27	0.48
3	Oxides of Nitrogen (NOx)	15	Crankcase Running Exhaust	Bin28	0.58
3	Oxides of Nitrogen (NOx)	15	Crankcase Running Exhaust	Bin29	0.70
3	Oxides of Nitrogen (NOx)	15	Crankcase Running Exhaust	Bin30	0.85
3	Oxides of Nitrogen (NOx)	15	Crankcase Running	Bin33	0.13

pollutantID	Pollutant Name	processID	Process Name	MOVESScenarioID	Emssion Rate (grams/hour)
			Exhaust		
3	Oxides of Nitrogen (NOx)	15	Crankcase Running Exhaust	Bin35	0.48
3	Oxides of Nitrogen (NOx)	15	Crankcase Running Exhaust	Bin37	0.74
3	Oxides of Nitrogen (NOx)	15	Crankcase Running Exhaust	Bin38	0.91
3	Oxides of Nitrogen (NOx)	15	Crankcase Running Exhaust	Bin39	1.11
3	Oxides of Nitrogen (NOx)	15	Crankcase Running Exhaust	Bin40	1.36
90	Atmospheric CO2	1	Running Exhaust	Bin0	15951.13
90	Atmospheric CO2	1	Running Exhaust	Bin1	7856.28
90	Atmospheric CO2	1	Running Exhaust	Bin11	10542.26
90	Atmospheric CO2	1	Running Exhaust	Bin12	30676.62
90	Atmospheric CO2	1	Running Exhaust	Bin13	56188.99
90	Atmospheric CO2	1	Running Exhaust	Bin14	81993.99
90	Atmospheric CO2	1	Running Exhaust	Bin15	103691.90
90	Atmospheric CO2	1	Running Exhaust	Bin16	142626.90
90	Atmospheric CO2	1	Running Exhaust	Bin21	6235.21
90	Atmospheric CO2	1	Running Exhaust	Bin22	28915.15
90	Atmospheric CO2	1	Running Exhaust	Bin23	47955.60
90	Atmospheric CO2	1	Running Exhaust	Bin24	69408.08
90	Atmospheric CO2	1	Running Exhaust	Bin25	89247.95
90	Atmospheric CO2	1	Running Exhaust	Bin27	123281.68
90	Atmospheric CO2	1	Running Exhaust	Bin28	172594.13
90	Atmospheric CO2	1	Running Exhaust	Bin29	221906.85
90	Atmospheric CO2	1	Running Exhaust	Bin30	271219.30
90	Atmospheric CO2	1	Running Exhaust	Bin33	35078.10
90	Atmospheric CO2	1	Running Exhaust	Bin35	107265.50
90	Atmospheric CO2	1	Running Exhaust	Bin37	167889.00
90	Atmospheric CO2	1	Running Exhaust	Bin38	235045.50
90	Atmospheric CO2	1	Running Exhaust	Bin39	302200.00
90	Atmospheric CO2	1	Running Exhaust	Bin40	369355.50
91	Total Energy Consumption	1	Running Exhaust	Bin0	217514.70
91	Total Energy Consumption	1	Running Exhaust	Bin1	107130.92
91	Total Energy Consumption	1	Running Exhaust	Bin11	143757.90
91	Total Energy Consumption	1	Running Exhaust	Bin12	418317.90
91	Total Energy Consumption	1	Running Exhaust	Bin13	766212.20
91	Total Energy Consumption	1	Running Exhaust	Bin14	1118101.40
91	Total Energy Consumption	1	Running Exhaust	Bin15	1413984.00
91	Total Energy Consumption	1	Running Exhaust	Bin16	1944930.00
91	Total Energy Consumption	1	Running Exhaust	Bin21	85025.33
91	Total Energy Consumption	1	Running Exhaust	Bin22	394297.75
91	Total Energy Consumption	1	Running Exhaust	Bin23	653939.00
91	Total Energy Consumption	1	Running Exhaust	Bin24	946475.75
91	Total Energy Consumption	1	Running Exhaust	Bin25	1217018.00

pollutantID	Pollutant Name	processID	Process Name	MOVESScenarioID	Emssion Rate (grams/hour)
91	Total Energy Consumption	1	Running Exhaust	Bin27	1681113.50
91	Total Energy Consumption	1	Running Exhaust	Bin28	2353560.00
91	Total Energy Consumption	1	Running Exhaust	Bin29	3026017.50
91	Total Energy Consumption	1	Running Exhaust	Bin30	3698447.50
91	Total Energy Consumption	1	Running Exhaust	Bin33	478338.00
91	Total Energy Consumption	1	Running Exhaust	Bin35	1462710.00
91	Total Energy Consumption	1	Running Exhaust	Bin37	2289400.00
91	Total Energy Consumption	1	Running Exhaust	Bin38	3205165.00
91	Total Energy Consumption	1	Running Exhaust	Bin39	4120915.00
91	Total Energy Consumption	1	Running Exhaust	Bin40	5036650.00
98	CO2 Equivalent	1	Running Exhaust	Bin0	15951.13
98	CO2 Equivalent	1	Running Exhaust	Bin1	7856.28
98	CO2 Equivalent	1	Running Exhaust	Bin11	10542.26
98	CO2 Equivalent	1	Running Exhaust	Bin12	30676.62
98	CO2 Equivalent	1	Running Exhaust	Bin13	56188.99
98	CO2 Equivalent	1	Running Exhaust	Bin14	81993.99
98	CO2 Equivalent	1	Running Exhaust	Bin15	103691.90
98	CO2 Equivalent	1	Running Exhaust	Bin16	142626.90
98	CO2 Equivalent	1	Running Exhaust	Bin21	6235.21
98	CO2 Equivalent	1	Running Exhaust	Bin22	28915.15
98	CO2 Equivalent	1	Running Exhaust	Bin23	47955.60
98	CO2 Equivalent	1	Running Exhaust	Bin24	69408.08
98	CO2 Equivalent	1	Running Exhaust	Bin25	89247.95
98	CO2 Equivalent	1	Running Exhaust	Bin27	123281.68
98	CO2 Equivalent	1	Running Exhaust	Bin28	172594.13
98	CO2 Equivalent	1	Running Exhaust	Bin29	221906.85
98	CO2 Equivalent	1	Running Exhaust	Bin30	271219.30
98	CO2 Equivalent	1	Running Exhaust	Bin33	35078.10
98	CO2 Equivalent	1	Running Exhaust	Bin35	107265.50
98	CO2 Equivalent	1	Running Exhaust	Bin37	167889.00
98	CO2 Equivalent	1	Running Exhaust	Bin38	235045.50
98	CO2 Equivalent	1	Running Exhaust	Bin39	302200.00
98	CO2 Equivalent	1	Running Exhaust	Bin40	369355.50
100	Primary Exhaust PM10 - Total	1	Running Exhaust	Bin0	5.80
100	Primary Exhaust PM10 - Total	1	Running Exhaust	Bin1	6.33
100	Primary Exhaust PM10 - Total	1	Running Exhaust	Bin11	5.49
100	Primary Exhaust PM10 - Total	1	Running Exhaust	Bin12	11.87
100	Primary Exhaust PM10 - Total	1	Running Exhaust	Bin13	27.45
100	Primary Exhaust PM10 - Total	1	Running Exhaust	Bin14	31.08
100	Primary Exhaust PM10 - Total	1	Running Exhaust	Bin15	44.30
100	Primary Exhaust PM10 - Total	1	Running Exhaust	Bin16	44.32
100	Primary Exhaust PM10 - Total	1	Running Exhaust	Bin21	4.58
100	Primary Exhaust PM10 - Total	1	Running Exhaust	Bin22	13.95
100	Primary Exhaust PM10 - Total	1	Running Exhaust	Bin23	18.77

pollutantID	Pollutant Name	processID	Process Name	MOVESScenarioID	Emssion Rate (grams/hour)
100	Primary Exhaust PM10 - Total	1	Running Exhaust	Bin24	29.71
100	Primary Exhaust PM10 - Total	1	Running Exhaust	Bin25	40.98
100	Primary Exhaust PM10 - Total	1	Running Exhaust	Bin27	52.17
100	Primary Exhaust PM10 - Total	1	Running Exhaust	Bin28	72.64
100	Primary Exhaust PM10 - Total	1	Running Exhaust	Bin29	102.05
100	Primary Exhaust PM10 - Total	1	Running Exhaust	Bin30	121.32
100	Primary Exhaust PM10 - Total	1	Running Exhaust	Bin33	0.02
100	Primary Exhaust PM10 - Total	1	Running Exhaust	Bin35	27.76
100	Primary Exhaust PM10 - Total	1	Running Exhaust	Bin37	37.52
100	Primary Exhaust PM10 - Total	1	Running Exhaust	Bin38	51.38
100	Primary Exhaust PM10 - Total	1	Running Exhaust	Bin39	71.17
100	Primary Exhaust PM10 - Total	1	Running Exhaust	Bin40	84.10
100	Primary Exhaust PM10 - Total	15	Crankcase Running Exhaust	Bin0	1.16
100	Primary Exhaust PM10 - Total	15	Crankcase Running Exhaust	Bin1	1.27
100	Primary Exhaust PM10 - Total	15	Crankcase Running Exhaust	Bin11	1.10
100	Primary Exhaust PM10 - Total	15	Crankcase Running Exhaust	Bin12	2.37
100	Primary Exhaust PM10 - Total	15	Crankcase Running Exhaust	Bin13	5.49
100	Primary Exhaust PM10 - Total	15	Crankcase Running Exhaust	Bin14	6.22
100	Primary Exhaust PM10 - Total	15	Crankcase Running Exhaust	Bin15	8.86
100	Primary Exhaust PM10 - Total	15	Crankcase Running Exhaust	Bin16	8.86
100	Primary Exhaust PM10 - Total	15	Crankcase Running Exhaust	Bin21	0.92
100	Primary Exhaust PM10 - Total	15	Crankcase Running Exhaust	Bin22	2.79
100	Primary Exhaust PM10 - Total	15	Crankcase Running Exhaust	Bin23	3.75
100	Primary Exhaust PM10 - Total	15	Crankcase Running Exhaust	Bin24	5.94
100	Primary Exhaust PM10 - Total	15	Crankcase Running Exhaust	Bin25	8.20
100	Primary Exhaust PM10 - Total	15	Crankcase Running Exhaust	Bin27	10.43
100	Primary Exhaust PM10 - Total	15	Crankcase Running Exhaust	Bin28	14.53
100	Primary Exhaust PM10 - Total	15	Crankcase Running Exhaust	Bin29	20.41
100	Primary Exhaust PM10 - Total	15	Crankcase Running Exhaust	Bin30	24.26
100	Primary Exhaust PM10 - Total	15	Crankcase Running Exhaust	Bin33	0.00
100	Primary Exhaust PM10 - Total	15	Crankcase Running Exhaust	Bin35	5.55
100	Primary Exhaust PM10 - Total	15	Crankcase Running Exhaust	Bin37	7.50
100	Primary Exhaust PM10 - Total	15	Crankcase Running	Bin38	10.28

pollutantID	Pollutant Name	processID	Process Name	MOVESScenarioID	Emssion Rate (grams/hour)
			Exhaust		
100	Primary Exhaust PM10 - Total	15	Crankcase Running Exhaust	Bin39	14.23
100	Primary Exhaust PM10 - Total	15	Crankcase Running Exhaust	Bin40	16.82
101	Primary PM10 - Organic Carbon	1	Running Exhaust	Bin0	4.13
101	Primary PM10 - Organic Carbon	1	Running Exhaust	Bin1	4.30
101	Primary PM10 - Organic Carbon	1	Running Exhaust	Bin11	3.98
101	Primary PM10 - Organic Carbon	1	Running Exhaust	Bin12	7.88
101	Primary PM10 - Organic Carbon	1	Running Exhaust	Bin13	5.84
101	Primary PM10 - Organic Carbon	1	Running Exhaust	Bin14	2.50
101	Primary PM10 - Organic Carbon	1	Running Exhaust	Bin15	2.72
101	Primary PM10 - Organic Carbon	1	Running Exhaust	Bin16	1.54
101	Primary PM10 - Organic Carbon	1	Running Exhaust	Bin21	3.41
101	Primary PM10 - Organic Carbon	1	Running Exhaust	Bin22	9.52
101	Primary PM10 - Organic Carbon	1	Running Exhaust	Bin23	5.90
101	Primary PM10 - Organic Carbon	1	Running Exhaust	Bin24	3.58
101	Primary PM10 - Organic Carbon	1	Running Exhaust	Bin25	2.64
101	Primary PM10 - Organic Carbon	1	Running Exhaust	Bin27	2.03
101	Primary PM10 - Organic Carbon	1	Running Exhaust	Bin28	2.38
101	Primary PM10 - Organic Carbon	1	Running Exhaust	Bin29	3.34
101	Primary PM10 - Organic Carbon	1	Running Exhaust	Bin30	3.97
101	Primary PM10 - Organic Carbon	1	Running Exhaust	Bin33	0.00
101	Primary PM10 - Organic Carbon	1	Running Exhaust	Bin35	2.81
101	Primary PM10 - Organic Carbon	1	Running Exhaust	Bin37	1.29
101	Primary PM10 - Organic Carbon	1	Running Exhaust	Bin38	1.76
101	Primary PM10 - Organic Carbon	1	Running Exhaust	Bin39	2.44
101	Primary PM10 - Organic Carbon	1	Running Exhaust	Bin40	2.89
101	Primary PM10 - Organic Carbon	15	Crankcase Running Exhaust	Bin0	0.83
101	Primary PM10 - Organic Carbon	15	Crankcase Running Exhaust	Bin1	0.86
101	Primary PM10 - Organic Carbon	15	Crankcase Running Exhaust	Bin11	0.80
101	Primary PM10 - Organic Carbon	15	Crankcase Running Exhaust	Bin12	1.58
101	Primary PM10 - Organic Carbon	15	Crankcase Running Exhaust	Bin13	1.17
101	Primary PM10 - Organic Carbon	15	Crankcase Running Exhaust	Bin14	0.50
101	Primary PM10 - Organic Carbon	15	Crankcase Running Exhaust	Bin15	0.54
101	Primary PM10 - Organic Carbon	15	Crankcase Running Exhaust	Bin16	0.31
101	Primary PM10 - Organic Carbon	15	Crankcase Running Exhaust	Bin21	0.68
101	Primary PM10 - Organic Carbon	15	Crankcase Running Exhaust	Bin22	1.90
101	Primary PM10 - Organic Carbon	15	Crankcase Running Exhaust	Bin23	1.18

pollutantID	Pollutant Name	processID	Process Name	MOVESScenarioID	Emssion Rate (grams/hour)
101	Primary PM10 - Organic Carbon	15	Crankcase Running Exhaust	Bin24	0.72
101	Primary PM10 - Organic Carbon	15	Crankcase Running Exhaust	Bin25	0.53
101	Primary PM10 - Organic Carbon	15	Crankcase Running Exhaust	Bin27	0.41
101	Primary PM10 - Organic Carbon	15	Crankcase Running Exhaust	Bin28	0.48
101	Primary PM10 - Organic Carbon	15	Crankcase Running Exhaust	Bin29	0.67
101	Primary PM10 - Organic Carbon	15	Crankcase Running Exhaust	Bin30	0.79
101	Primary PM10 - Organic Carbon	15	Crankcase Running Exhaust	Bin33	0.00
101	Primary PM10 - Organic Carbon	15	Crankcase Running Exhaust	Bin35	0.56
101	Primary PM10 - Organic Carbon	15	Crankcase Running Exhaust	Bin37	0.26
101	Primary PM10 - Organic Carbon	15	Crankcase Running Exhaust	Bin38	0.35
101	Primary PM10 - Organic Carbon	15	Crankcase Running Exhaust	Bin39	0.49
101	Primary PM10 - Organic Carbon	15	Crankcase Running Exhaust	Bin40	0.58
102	Primary PM10 - Elemental Carbon	1	Running Exhaust	Bin0	1.66
102	Primary PM10 - Elemental Carbon	1	Running Exhaust	Bin1	2.03
102	Primary PM10 - Elemental Carbon	1	Running Exhaust	Bin11	1.51
102	Primary PM10 - Elemental Carbon	1	Running Exhaust	Bin12	3.97
102	Primary PM10 - Elemental Carbon	1	Running Exhaust	Bin13	21.58
102	Primary PM10 - Elemental Carbon	1	Running Exhaust	Bin14	28.54
102	Primary PM10 - Elemental Carbon	1	Running Exhaust	Bin15	41.52
102	Primary PM10 - Elemental Carbon	1	Running Exhaust	Bin16	42.71
102	Primary PM10 - Elemental Carbon	1	Running Exhaust	Bin21	1.16
102	Primary PM10 - Elemental Carbon	1	Running Exhaust	Bin22	4.42
102	Primary PM10 - Elemental Carbon	1	Running Exhaust	Bin23	12.84
102	Primary PM10 - Elemental Carbon	1	Running Exhaust	Bin24	26.09
102	Primary PM10 - Elemental Carbon	1	Running Exhaust	Bin25	38.30
102	Primary PM10 - Elemental Carbon	1	Running Exhaust	Bin27	50.08
102	Primary PM10 - Elemental Carbon	1	Running Exhaust	Bin28	70.17
102	Primary PM10 - Elemental Carbon	1	Running Exhaust	Bin29	98.60
102	Primary PM10 - Elemental Carbon	1	Running Exhaust	Bin30	117.21
102	Primary PM10 - Elemental Carbon	1	Running Exhaust	Bin33	0.00
102	Primary PM10 - Elemental Carbon	1	Running Exhaust	Bin35	24.89
102	Primary PM10 - Elemental Carbon	1	Running Exhaust	Bin37	36.15
102	Primary PM10 - Elemental Carbon	1	Running Exhaust	Bin38	49.50
102	Primary PM10 - Elemental Carbon	1	Running Exhaust	Bin39	68.58
102	Primary PM10 - Elemental Carbon	1	Running Exhaust	Bin40	81.03
102	Primary PM10 - Elemental Carbon	15	Crankcase Running Exhaust	Bin0	0.33
102	Primary PM10 - Elemental Carbon	15	Crankcase Running	Bin1	0.41

pollutantID	Pollutant Name	processID	Process Name	MOVESScenarioID	Emssion Rate (grams/hour)
			Exhaust		
102	Primary PM10 - Elemental Carbon	15	Crankcase Running Exhaust	Bin11	0.30
102	Primary PM10 - Elemental Carbon	15	Crankcase Running Exhaust	Bin12	0.79
102	Primary PM10 - Elemental Carbon	15	Crankcase Running Exhaust	Bin13	4.32
102	Primary PM10 - Elemental Carbon	15	Crankcase Running Exhaust	Bin14	5.71
102	Primary PM10 - Elemental Carbon	15	Crankcase Running Exhaust	Bin15	8.30
102	Primary PM10 - Elemental Carbon	15	Crankcase Running Exhaust	Bin16	8.54
102	Primary PM10 - Elemental Carbon	15	Crankcase Running Exhaust	Bin21	0.23
102	Primary PM10 - Elemental Carbon	15	Crankcase Running Exhaust	Bin22	0.88
102	Primary PM10 - Elemental Carbon	15	Crankcase Running Exhaust	Bin23	2.57
102	Primary PM10 - Elemental Carbon	15	Crankcase Running Exhaust	Bin24	5.22
102	Primary PM10 - Elemental Carbon	15	Crankcase Running Exhaust	Bin25	7.66
102	Primary PM10 - Elemental Carbon	15	Crankcase Running Exhaust	Bin27	10.02
102	Primary PM10 - Elemental Carbon	15	Crankcase Running Exhaust	Bin28	14.03
102	Primary PM10 - Elemental Carbon	15	Crankcase Running Exhaust	Bin29	19.72
102	Primary PM10 - Elemental Carbon	15	Crankcase Running Exhaust	Bin30	23.44
102	Primary PM10 - Elemental Carbon	15	Crankcase Running Exhaust	Bin33	0.00
102	Primary PM10 - Elemental Carbon	15	Crankcase Running Exhaust	Bin35	4.98
102	Primary PM10 - Elemental Carbon	15	Crankcase Running Exhaust	Bin37	7.23
102	Primary PM10 - Elemental Carbon	15	Crankcase Running Exhaust	Bin38	9.90
102	Primary PM10 - Elemental Carbon	15	Crankcase Running Exhaust	Bin39	13.72
102	Primary PM10 - Elemental Carbon	15	Crankcase Running Exhaust	Bin40	16.21
105	Primary PM10 - Sulfate Particulate	1	Running Exhaust	Bin0	0.01
105	Primary PM10 - Sulfate Particulate	1	Running Exhaust	Bin1	0.00
105	Primary PM10 - Sulfate Particulate	1	Running Exhaust	Bin11	0.01
105	Primary PM10 - Sulfate Particulate	1	Running Exhaust	Bin12	0.02
105	Primary PM10 - Sulfate Particulate	1	Running Exhaust	Bin13	0.03
105	Primary PM10 - Sulfate Particulate	1	Running Exhaust	Bin14	0.04
105	Primary PM10 - Sulfate Particulate	1	Running Exhaust	Bin15	0.05
105	Primary PM10 - Sulfate Particulate	1	Running Exhaust	Bin16	0.07
105	Primary PM10 - Sulfate Particulate	1	Running Exhaust	Bin21	0.00
105	Primary PM10 - Sulfate Particulate	1	Running Exhaust	Bin22	0.01

pollutantID	Pollutant Name	processID	Process Name	MOVESScenarioID	Emssion Rate (grams/hour)
105	Primary PM10 - Sulfate Particulate	1	Running Exhaust	Bin23	0.02
105	Primary PM10 - Sulfate Particulate	1	Running Exhaust	Bin24	0.03
105	Primary PM10 - Sulfate Particulate	1	Running Exhaust	Bin25	0.04
105	Primary PM10 - Sulfate Particulate	1	Running Exhaust	Bin27	0.06
105	Primary PM10 - Sulfate Particulate	1	Running Exhaust	Bin28	0.08
105	Primary PM10 - Sulfate Particulate	1	Running Exhaust	Bin29	0.11
105	Primary PM10 - Sulfate Particulate	1	Running Exhaust	Bin30	0.13
105	Primary PM10 - Sulfate Particulate	1	Running Exhaust	Bin33	0.02
105	Primary PM10 - Sulfate Particulate	1	Running Exhaust	Bin35	0.05
105	Primary PM10 - Sulfate Particulate	1	Running Exhaust	Bin37	0.08
105	Primary PM10 - Sulfate Particulate	1	Running Exhaust	Bin38	0.12
105	Primary PM10 - Sulfate Particulate	1	Running Exhaust	Bin39	0.15
105	Primary PM10 - Sulfate Particulate	1	Running Exhaust	Bin40	0.18
105	Primary PM10 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin0	0.00
105	Primary PM10 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin1	0.00
105	Primary PM10 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin11	0.00
105	Primary PM10 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin12	0.00
105	Primary PM10 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin13	0.01
105	Primary PM10 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin14	0.01
105	Primary PM10 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin15	0.01
105	Primary PM10 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin16	0.01
105	Primary PM10 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin21	0.00
105	Primary PM10 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin22	0.00
105	Primary PM10 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin23	0.00
105	Primary PM10 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin24	0.01
105	Primary PM10 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin25	0.01
105	Primary PM10 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin27	0.01
105	Primary PM10 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin28	0.02
105	Primary PM10 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin29	0.02
105	Primary PM10 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin30	0.03
105	Primary PM10 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin33	0.00
105	Primary PM10 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin35	0.01
105	Primary PM10 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin37	0.02

pollutantID	Pollutant Name	processID	Process Name	MOVESScenarioID	Emssion Rate (grams/hour)
105	Primary PM10 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin38	0.02
105	Primary PM10 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin39	0.03
105	Primary PM10 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin40	0.04
106	Primary PM10 - Brakewear Particulate	9	Brakewear	Bin0	13.04
106	Primary PM10 - Brakewear Particulate	9	Brakewear	Bin1	0.25
106	Primary PM10 - Brakewear Particulate	9	Brakewear	Bin11	12.79
106	Primary PM10 - Brakewear Particulate	9	Brakewear	Bin12	0.00
106	Primary PM10 - Brakewear Particulate	9	Brakewear	Bin13	0.00
106	Primary PM10 - Brakewear Particulate	9	Brakewear	Bin14	0.00
106	Primary PM10 - Brakewear Particulate	9	Brakewear	Bin15	0.00
106	Primary PM10 - Brakewear Particulate	9	Brakewear	Bin16	0.00
106	Primary PM10 - Brakewear Particulate	9	Brakewear	Bin21	6.31
106	Primary PM10 - Brakewear Particulate	9	Brakewear	Bin22	0.00
106	Primary PM10 - Brakewear Particulate	9	Brakewear	Bin23	0.00
106	Primary PM10 - Brakewear Particulate	9	Brakewear	Bin24	0.00
106	Primary PM10 - Brakewear Particulate	9	Brakewear	Bin25	0.00
106	Primary PM10 - Brakewear Particulate	9	Brakewear	Bin27	0.00
106	Primary PM10 - Brakewear Particulate	9	Brakewear	Bin28	0.00
106	Primary PM10 - Brakewear Particulate	9	Brakewear	Bin29	0.00
106	Primary PM10 - Brakewear Particulate	9	Brakewear	Bin30	0.00
106	Primary PM10 - Brakewear Particulate	9	Brakewear	Bin33	0.00
106	Primary PM10 - Brakewear Particulate	9	Brakewear	Bin35	0.00
106	Primary PM10 - Brakewear Particulate	9	Brakewear	Bin37	0.00
106	Primary PM10 - Brakewear Particulate	9	Brakewear	Bin38	0.00
106	Primary PM10 - Brakewear Particulate	9	Brakewear	Bin39	0.00
106	Primary PM10 - Brakewear Particulate	9	Brakewear	Bin40	0.00
107	Primary PM10 - Tirewear Particulate	10	Tirewear	Bin0	0.00
107	Primary PM10 - Tirewear Particulate	10	Tirewear	Bin1	0.00
107	Primary PM10 - Tirewear Particulate	10	Tirewear	Bin11	0.00
107	Primary PM10 - Tirewear Particulate	10	Tirewear	Bin12	0.00

pollutantID	Pollutant Name	processID	Process Name	MOVESScenarioID	Emssion Rate (grams/hour)
107	Primary PM10 - Tirewear Particulate	10	Tirewear	Bin13	0.00
107	Primary PM10 - Tirewear Particulate	10	Tirewear	Bin14	0.00
107	Primary PM10 - Tirewear Particulate	10	Tirewear	Bin15	0.00
107	Primary PM10 - Tirewear Particulate	10	Tirewear	Bin16	0.00
107	Primary PM10 - Tirewear Particulate	10	Tirewear	Bin21	0.00
107	Primary PM10 - Tirewear Particulate	10	Tirewear	Bin22	0.00
107	Primary PM10 - Tirewear Particulate	10	Tirewear	Bin23	0.00
107	Primary PM10 - Tirewear Particulate	10	Tirewear	Bin24	0.00
107	Primary PM10 - Tirewear Particulate	10	Tirewear	Bin25	0.00
107	Primary PM10 - Tirewear Particulate	10	Tirewear	Bin27	0.00
107	Primary PM10 - Tirewear Particulate	10	Tirewear	Bin28	0.00
107	Primary PM10 - Tirewear Particulate	10	Tirewear	Bin29	0.00
107	Primary PM10 - Tirewear Particulate	10	Tirewear	Bin30	0.00
107	Primary PM10 - Tirewear Particulate	10	Tirewear	Bin33	0.00
107	Primary PM10 - Tirewear Particulate	10	Tirewear	Bin35	0.00
107	Primary PM10 - Tirewear Particulate	10	Tirewear	Bin37	0.00
107	Primary PM10 - Tirewear Particulate	10	Tirewear	Bin38	0.00
107	Primary PM10 - Tirewear Particulate	10	Tirewear	Bin39	0.00
107	Primary PM10 - Tirewear Particulate	10	Tirewear	Bin40	0.00
110	Primary Exhaust PM2.5 - Total	1	Running Exhaust	Bin0	5.62
110	Primary Exhaust PM2.5 - Total	1	Running Exhaust	Bin1	6.14
110	Primary Exhaust PM2.5 - Total	1	Running Exhaust	Bin11	5.33
110	Primary Exhaust PM2.5 - Total	1	Running Exhaust	Bin12	11.51
110	Primary Exhaust PM2.5 - Total	1	Running Exhaust	Bin13	26.62
110	Primary Exhaust PM2.5 - Total	1	Running Exhaust	Bin14	30.15
110	Primary Exhaust PM2.5 - Total	1	Running Exhaust	Bin15	42.97
110	Primary Exhaust PM2.5 - Total	1	Running Exhaust	Bin16	42.99
110	Primary Exhaust PM2.5 - Total	1	Running Exhaust	Bin21	4.44
110	Primary Exhaust PM2.5 - Total	1	Running Exhaust	Bin22	13.53
110	Primary Exhaust PM2.5 - Total	1	Running Exhaust	Bin23	18.21
110	Primary Exhaust PM2.5 - Total	1	Running Exhaust	Bin24	28.82
110	Primary Exhaust PM2.5 - Total	1	Running Exhaust	Bin25	39.75
110	Primary Exhaust PM2.5 - Total	1	Running Exhaust	Bin27	50.61
110	Primary Exhaust PM2.5 - Total	1	Running Exhaust	Bin28	70.46
110	Primary Exhaust PM2.5 - Total	1	Running Exhaust	Bin29	98.99
110	Primary Exhaust PM2.5 - Total	1	Running Exhaust	Bin30	117.68
110	Primary Exhaust PM2.5 - Total	1	Running Exhaust	Bin33	0.02
110	Primary Exhaust PM2.5 - Total	1	Running Exhaust	Bin35	26.93
110	Primary Exhaust PM2.5 - Total	1	Running Exhaust	Bin37	36.39
110	Primary Exhaust PM2.5 - Total	1	Running Exhaust	Bin38	49.84
110	Primary Exhaust PM2.5 - Total	1	Running Exhaust	Bin39	69.04
110	Primary Exhaust PM2.5 - Total	1	Running Exhaust	Bin40	81.58
110	Primary Exhaust PM2.5 - Total	15	Crankcase Running Exhaust	Bin0	1.12
110	Primary Exhaust PM2.5 - Total	15	Crankcase Running	Bin1	1.23

pollutantID	Pollutant Name	processID	Process Name	MOVESScenarioID	Emssion Rate (grams/hour)
			Exhaust		
110	Primary Exhaust PM2.5 - Total	15	Crankcase Running Exhaust	Bin11	1.07
110	Primary Exhaust PM2.5 - Total	15	Crankcase Running Exhaust	Bin12	2.30
110	Primary Exhaust PM2.5 - Total	15	Crankcase Running Exhaust	Bin13	5.32
110	Primary Exhaust PM2.5 - Total	15	Crankcase Running Exhaust	Bin14	6.03
110	Primary Exhaust PM2.5 - Total	15	Crankcase Running Exhaust	Bin15	8.59
110	Primary Exhaust PM2.5 - Total	15	Crankcase Running Exhaust	Bin16	8.60
110	Primary Exhaust PM2.5 - Total	15	Crankcase Running Exhaust	Bin21	0.89
110	Primary Exhaust PM2.5 - Total	15	Crankcase Running Exhaust	Bin22	2.71
110	Primary Exhaust PM2.5 - Total	15	Crankcase Running Exhaust	Bin23	3.64
110	Primary Exhaust PM2.5 - Total	15	Crankcase Running Exhaust	Bin24	5.76
110	Primary Exhaust PM2.5 - Total	15	Crankcase Running Exhaust	Bin25	7.95
110	Primary Exhaust PM2.5 - Total	15	Crankcase Running Exhaust	Bin27	10.12
110	Primary Exhaust PM2.5 - Total	15	Crankcase Running Exhaust	Bin28	14.09
110	Primary Exhaust PM2.5 - Total	15	Crankcase Running Exhaust	Bin29	19.80
110	Primary Exhaust PM2.5 - Total	15	Crankcase Running Exhaust	Bin30	23.54
110	Primary Exhaust PM2.5 - Total	15	Crankcase Running Exhaust	Bin33	0.00
110	Primary Exhaust PM2.5 - Total	15	Crankcase Running Exhaust	Bin35	5.39
110	Primary Exhaust PM2.5 - Total	15	Crankcase Running Exhaust	Bin37	7.28
110	Primary Exhaust PM2.5 - Total	15	Crankcase Running Exhaust	Bin38	9.97
110	Primary Exhaust PM2.5 - Total	15	Crankcase Running Exhaust	Bin39	13.81
110	Primary Exhaust PM2.5 - Total	15	Crankcase Running Exhaust	Bin40	16.32
111	Primary PM2.5 - Organic Carbon	1	Running Exhaust	Bin0	4.00
111	Primary PM2.5 - Organic Carbon	1	Running Exhaust	Bin1	4.17
111	Primary PM2.5 - Organic Carbon	1	Running Exhaust	Bin11	3.86
111	Primary PM2.5 - Organic Carbon	1	Running Exhaust	Bin12	7.64
111	Primary PM2.5 - Organic Carbon	1	Running Exhaust	Bin13	5.66
111	Primary PM2.5 - Organic Carbon	1	Running Exhaust	Bin14	2.43
111	Primary PM2.5 - Organic Carbon	1	Running Exhaust	Bin15	2.64
111	Primary PM2.5 - Organic Carbon	1	Running Exhaust	Bin16	1.49
111	Primary PM2.5 - Organic Carbon	1	Running Exhaust	Bin21	3.31
111	Primary PM2.5 - Organic Carbon	1	Running Exhaust	Bin22	9.23

pollutantID	Pollutant Name	processID	Process Name	MOVESScenarioID	Emssion Rate (grams/hour)
111	Primary PM2.5 - Organic Carbon	1	Running Exhaust	Bin23	5.72
111	Primary PM2.5 - Organic Carbon	1	Running Exhaust	Bin24	3.47
111	Primary PM2.5 - Organic Carbon	1	Running Exhaust	Bin25	2.56
111	Primary PM2.5 - Organic Carbon	1	Running Exhaust	Bin27	1.97
111	Primary PM2.5 - Organic Carbon	1	Running Exhaust	Bin28	2.31
111	Primary PM2.5 - Organic Carbon	1	Running Exhaust	Bin29	3.24
111	Primary PM2.5 - Organic Carbon	1	Running Exhaust	Bin30	3.85
111	Primary PM2.5 - Organic Carbon	1	Running Exhaust	Bin33	0.00
111	Primary PM2.5 - Organic Carbon	1	Running Exhaust	Bin35	2.73
111	Primary PM2.5 - Organic Carbon	1	Running Exhaust	Bin37	1.25
111	Primary PM2.5 - Organic Carbon	1	Running Exhaust	Bin38	1.71
111	Primary PM2.5 - Organic Carbon	1	Running Exhaust	Bin39	2.37
111	Primary PM2.5 - Organic Carbon	1	Running Exhaust	Bin40	2.80
111	Primary PM2.5 - Organic Carbon	15	Crankcase Running Exhaust	Bin0	0.80
111	Primary PM2.5 - Organic Carbon	15	Crankcase Running Exhaust	Bin1	0.83
111	Primary PM2.5 - Organic Carbon	15	Crankcase Running Exhaust	Bin11	0.77
111	Primary PM2.5 - Organic Carbon	15	Crankcase Running Exhaust	Bin12	1.53
111	Primary PM2.5 - Organic Carbon	15	Crankcase Running Exhaust	Bin13	1.13
111	Primary PM2.5 - Organic Carbon	15	Crankcase Running Exhaust	Bin14	0.49
111	Primary PM2.5 - Organic Carbon	15	Crankcase Running Exhaust	Bin15	0.53
111	Primary PM2.5 - Organic Carbon	15	Crankcase Running Exhaust	Bin16	0.30
111	Primary PM2.5 - Organic Carbon	15	Crankcase Running Exhaust	Bin21	0.66
111	Primary PM2.5 - Organic Carbon	15	Crankcase Running Exhaust	Bin22	1.85
111	Primary PM2.5 - Organic Carbon	15	Crankcase Running Exhaust	Bin23	1.14
111	Primary PM2.5 - Organic Carbon	15	Crankcase Running Exhaust	Bin24	0.69
111	Primary PM2.5 - Organic Carbon	15	Crankcase Running Exhaust	Bin25	0.51
111	Primary PM2.5 - Organic Carbon	15	Crankcase Running Exhaust	Bin27	0.39
111	Primary PM2.5 - Organic Carbon	15	Crankcase Running Exhaust	Bin28	0.46
111	Primary PM2.5 - Organic Carbon	15	Crankcase Running Exhaust	Bin29	0.65
111	Primary PM2.5 - Organic Carbon	15	Crankcase Running Exhaust	Bin30	0.77
111	Primary PM2.5 - Organic Carbon	15	Crankcase Running Exhaust	Bin33	0.00
111	Primary PM2.5 - Organic Carbon	15	Crankcase Running Exhaust	Bin35	0.55
111	Primary PM2.5 - Organic Carbon	15	Crankcase Running Exhaust	Bin37	0.25

pollutantID	Pollutant Name	processID	Process Name	MOVESScenarioID	Emssion Rate (grams/hour)
111	Primary PM2.5 - Organic Carbon	15	Crankcase Running Exhaust	Bin38	0.34
111	Primary PM2.5 - Organic Carbon	15	Crankcase Running Exhaust	Bin39	0.47
111	Primary PM2.5 - Organic Carbon	15	Crankcase Running Exhaust	Bin40	0.56
112	Primary PM2.5 - Elemental Carbon	1	Running Exhaust	Bin0	1.61
112	Primary PM2.5 - Elemental Carbon	1	Running Exhaust	Bin1	1.97
112	Primary PM2.5 - Elemental Carbon	1	Running Exhaust	Bin11	1.46
112	Primary PM2.5 - Elemental Carbon	1	Running Exhaust	Bin12	3.85
112	Primary PM2.5 - Elemental Carbon	1	Running Exhaust	Bin13	20.93
112	Primary PM2.5 - Elemental Carbon	1	Running Exhaust	Bin14	27.68
112	Primary PM2.5 - Elemental Carbon	1	Running Exhaust	Bin15	40.28
112	Primary PM2.5 - Elemental Carbon	1	Running Exhaust	Bin16	41.43
112	Primary PM2.5 - Elemental Carbon	1	Running Exhaust	Bin21	1.12
112	Primary PM2.5 - Elemental Carbon	1	Running Exhaust	Bin22	4.29
112	Primary PM2.5 - Elemental Carbon	1	Running Exhaust	Bin23	12.46
112	Primary PM2.5 - Elemental Carbon	1	Running Exhaust	Bin24	25.31
112	Primary PM2.5 - Elemental Carbon	1	Running Exhaust	Bin25	37.15
112	Primary PM2.5 - Elemental Carbon	1	Running Exhaust	Bin27	48.58
112	Primary PM2.5 - Elemental Carbon	1	Running Exhaust	Bin28	68.07
112	Primary PM2.5 - Elemental Carbon	1	Running Exhaust	Bin29	95.65
112	Primary PM2.5 - Elemental Carbon	1	Running Exhaust	Bin30	113.70
112	Primary PM2.5 - Elemental Carbon	1	Running Exhaust	Bin33	0.00
112	Primary PM2.5 - Elemental Carbon	1	Running Exhaust	Bin35	24.15
112	Primary PM2.5 - Elemental Carbon	1	Running Exhaust	Bin37	35.06
112	Primary PM2.5 - Elemental Carbon	1	Running Exhaust	Bin38	48.02
112	Primary PM2.5 - Elemental Carbon	1	Running Exhaust	Bin39	66.53
112	Primary PM2.5 - Elemental Carbon	1	Running Exhaust	Bin40	78.60
112	Primary PM2.5 - Elemental Carbon	15	Crankcase Running Exhaust	Bin0	0.32
112	Primary PM2.5 - Elemental Carbon	15	Crankcase Running Exhaust	Bin1	0.39
112	Primary PM2.5 - Elemental Carbon	15	Crankcase Running Exhaust	Bin11	0.29
112	Primary PM2.5 - Elemental Carbon	15	Crankcase Running Exhaust	Bin12	0.77
112	Primary PM2.5 - Elemental Carbon	15	Crankcase Running Exhaust	Bin13	4.19
112	Primary PM2.5 - Elemental Carbon	15	Crankcase Running Exhaust	Bin14	5.54
112	Primary PM2.5 - Elemental Carbon	15	Crankcase Running Exhaust	Bin15	8.06
112	Primary PM2.5 - Elemental Carbon	15	Crankcase Running Exhaust	Bin16	8.29
112	Primary PM2.5 - Elemental Carbon	15	Crankcase Running Exhaust	Bin21	0.22
112	Primary PM2.5 - Elemental Carbon	15	Crankcase Running Exhaust	Bin22	0.86
112	Primary PM2.5 - Elemental Carbon	15	Crankcase Running	Bin23	2.49

pollutantID	Pollutant Name	processID	Process Name	MOVESScenarioID	Emssion Rate (grams/hour)
			Exhaust		
112	Primary PM2.5 - Elemental Carbon	15	Crankcase Running Exhaust	Bin24	5.06
112	Primary PM2.5 - Elemental Carbon	15	Crankcase Running Exhaust	Bin25	7.43
112	Primary PM2.5 - Elemental Carbon	15	Crankcase Running Exhaust	Bin27	9.72
112	Primary PM2.5 - Elemental Carbon	15	Crankcase Running Exhaust	Bin28	13.61
112	Primary PM2.5 - Elemental Carbon	15	Crankcase Running Exhaust	Bin29	19.13
112	Primary PM2.5 - Elemental Carbon	15	Crankcase Running Exhaust	Bin30	22.74
112	Primary PM2.5 - Elemental Carbon	15	Crankcase Running Exhaust	Bin33	0.00
112	Primary PM2.5 - Elemental Carbon	15	Crankcase Running Exhaust	Bin35	4.83
112	Primary PM2.5 - Elemental Carbon	15	Crankcase Running Exhaust	Bin37	7.01
112	Primary PM2.5 - Elemental Carbon	15	Crankcase Running Exhaust	Bin38	9.60
112	Primary PM2.5 - Elemental Carbon	15	Crankcase Running Exhaust	Bin39	13.31
112	Primary PM2.5 - Elemental Carbon	15	Crankcase Running Exhaust	Bin40	15.72
115	Primary PM2.5 - Sulfate Particulate	1	Running Exhaust	Bin0	0.01
115	Primary PM2.5 - Sulfate Particulate	1	Running Exhaust	Bin1	0.00
115	Primary PM2.5 - Sulfate Particulate	1	Running Exhaust	Bin11	0.01
115	Primary PM2.5 - Sulfate Particulate	1	Running Exhaust	Bin12	0.01
115	Primary PM2.5 - Sulfate Particulate	1	Running Exhaust	Bin13	0.03
115	Primary PM2.5 - Sulfate Particulate	1	Running Exhaust	Bin14	0.04
115	Primary PM2.5 - Sulfate Particulate	1	Running Exhaust	Bin15	0.05
115	Primary PM2.5 - Sulfate Particulate	1	Running Exhaust	Bin16	0.07
115	Primary PM2.5 - Sulfate Particulate	1	Running Exhaust	Bin21	0.00
115	Primary PM2.5 - Sulfate Particulate	1	Running Exhaust	Bin22	0.01
115	Primary PM2.5 - Sulfate Particulate	1	Running Exhaust	Bin23	0.02
115	Primary PM2.5 - Sulfate Particulate	1	Running Exhaust	Bin24	0.03
115	Primary PM2.5 - Sulfate Particulate	1	Running Exhaust	Bin25	0.04
115	Primary PM2.5 - Sulfate Particulate	1	Running Exhaust	Bin27	0.06
115	Primary PM2.5 - Sulfate Particulate	1	Running Exhaust	Bin28	0.08
115	Primary PM2.5 - Sulfate Particulate	1	Running Exhaust	Bin29	0.11
115	Primary PM2.5 - Sulfate Particulate	1	Running Exhaust	Bin30	0.13
115	Primary PM2.5 - Sulfate Particulate	1	Running Exhaust	Bin33	0.02
115	Primary PM2.5 - Sulfate Particulate	1	Running Exhaust	Bin35	0.05
115	Primary PM2.5 - Sulfate Particulate	1	Running Exhaust	Bin37	0.08
115	Primary PM2.5 - Sulfate Particulate	1	Running Exhaust	Bin38	0.11
115	Primary PM2.5 - Sulfate Particulate	1	Running Exhaust	Bin39	0.14
115	Primary PM2.5 - Sulfate Particulate	1	Running Exhaust	Bin40	0.18
115	Primary PM2.5 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin0	0.00

pollutantID	Pollutant Name	processID	Process Name	MOVESScenarioID	Emssion Rate (grams/hour)
115	Primary PM2.5 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin1	0.00
115	Primary PM2.5 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin11	0.00
115	Primary PM2.5 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin12	0.00
115	Primary PM2.5 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin13	0.01
115	Primary PM2.5 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin14	0.01
115	Primary PM2.5 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin15	0.01
115	Primary PM2.5 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin16	0.01
115	Primary PM2.5 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin21	0.00
115	Primary PM2.5 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin22	0.00
115	Primary PM2.5 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin23	0.00
115	Primary PM2.5 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin24	0.01
115	Primary PM2.5 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin25	0.01
115	Primary PM2.5 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin27	0.01
115	Primary PM2.5 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin28	0.02
115	Primary PM2.5 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin29	0.02
115	Primary PM2.5 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin30	0.03
115	Primary PM2.5 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin33	0.00
115	Primary PM2.5 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin35	0.01
115	Primary PM2.5 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin37	0.02
115	Primary PM2.5 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin38	0.02
115	Primary PM2.5 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin39	0.03
115	Primary PM2.5 - Sulfate Particulate	15	Crankcase Running Exhaust	Bin40	0.04
116	Primary PM2.5 - Brakewear Particulate	9	Brakewear	Bin0	3.41
116	Primary PM2.5 - Brakewear Particulate	9	Brakewear	Bin1	0.07
116	Primary PM2.5 - Brakewear Particulate	9	Brakewear	Bin11	3.35
116	Primary PM2.5 - Brakewear Particulate	9	Brakewear	Bin12	0.00
116	Primary PM2.5 - Brakewear Particulate	9	Brakewear	Bin13	0.00
116	Primary PM2.5 - Brakewear Particulate	9	Brakewear	Bin14	0.00

pollutantID	Pollutant Name	processID	Process Name	MOVESScenarioID	Emssion Rate (grams/hour)
116	Primary PM2.5 - Brakewear Particulate	9	Brakewear	Bin15	0.00
116	Primary PM2.5 - Brakewear Particulate	9	Brakewear	Bin16	0.00
116	Primary PM2.5 - Brakewear Particulate	9	Brakewear	Bin21	1.65
116	Primary PM2.5 - Brakewear Particulate	9	Brakewear	Bin22	0.00
116	Primary PM2.5 - Brakewear Particulate	9	Brakewear	Bin23	0.00
116	Primary PM2.5 - Brakewear Particulate	9	Brakewear	Bin24	0.00
116	Primary PM2.5 - Brakewear Particulate	9	Brakewear	Bin25	0.00
116	Primary PM2.5 - Brakewear Particulate	9	Brakewear	Bin27	0.00
116	Primary PM2.5 - Brakewear Particulate	9	Brakewear	Bin28	0.00
116	Primary PM2.5 - Brakewear Particulate	9	Brakewear	Bin29	0.00
116	Primary PM2.5 - Brakewear Particulate	9	Brakewear	Bin30	0.00
116	Primary PM2.5 - Brakewear Particulate	9	Brakewear	Bin33	0.00
116	Primary PM2.5 - Brakewear Particulate	9	Brakewear	Bin35	0.00
116	Primary PM2.5 - Brakewear Particulate	9	Brakewear	Bin37	0.00
116	Primary PM2.5 - Brakewear Particulate	9	Brakewear	Bin38	0.00
116	Primary PM2.5 - Brakewear Particulate	9	Brakewear	Bin39	0.00
116	Primary PM2.5 - Brakewear Particulate	9	Brakewear	Bin40	0.00
117	Primary PM2.5 - Tirewear Particulate	10	Tirewear	Bin0	0.00
117	Primary PM2.5 - Tirewear Particulate	10	Tirewear	Bin1	0.00
117	Primary PM2.5 - Tirewear Particulate	10	Tirewear	Bin11	0.00
117	Primary PM2.5 - Tirewear Particulate	10	Tirewear	Bin12	0.00
117	Primary PM2.5 - Tirewear Particulate	10	Tirewear	Bin13	0.00
117	Primary PM2.5 - Tirewear Particulate	10	Tirewear	Bin14	0.00
117	Primary PM2.5 - Tirewear Particulate	10	Tirewear	Bin15	0.00
117	Primary PM2.5 - Tirewear Particulate	10	Tirewear	Bin16	0.00
117	Primary PM2.5 - Tirewear Particulate	10	Tirewear	Bin21	0.00
117	Primary PM2.5 - Tirewear Particulate	10	Tirewear	Bin22	0.00
117	Primary PM2.5 - Tirewear Particulate	10	Tirewear	Bin23	0.00
117	Primary PM2.5 - Tirewear Particulate	10	Tirewear	Bin24	0.00
117	Primary PM2.5 - Tirewear Particulate	10	Tirewear	Bin25	0.00
117	Primary PM2.5 - Tirewear Particulate	10	Tirewear	Bin27	0.00
117	Primary PM2.5 - Tirewear Particulate	10	Tirewear	Bin28	0.00
117	Primary PM2.5 - Tirewear Particulate	10	Tirewear	Bin29	0.00
117	Primary PM2.5 - Tirewear Particulate	10	Tirewear	Bin30	0.00
117	Primary PM2.5 - Tirewear Particulate	10	Tirewear	Bin33	0.00

pollutantID	Pollutant Name	processID	Process Name	MOVESScenarioID	Emssion Rate (grams/hour)
117	Primary PM2.5 - Tirewear Particulate	10	Tirewear	Bin35	0.00
117	Primary PM2.5 - Tirewear Particulate	10	Tirewear	Bin37	0.00
117	Primary PM2.5 - Tirewear Particulate	10	Tirewear	Bin38	0.00
117	Primary PM2.5 - Tirewear Particulate	10	Tirewear	Bin39	0.00
117	Primary PM2.5 - Tirewear Particulate	10	Tirewear	Bin40	0.00

Table C.2: Idling Emission Rates for All Pollutant Processes by Operating Mode

pollutantID	Pollutant Name	processID	Process Name	MOVESScenarioID	Emssion Rate (grams/hour)
1	Total Gaseous Hydrocarbons	2	Start Exhaust	Bin1	0.61762
1	Total Gaseous Hydrocarbons	2	Start Exhaust	Bin200	0.61762
1	Total Gaseous Hydrocarbons	16	Crankcase Start Exhaust	Bin1	0.012352
1	Total Gaseous Hydrocarbons	16	Crankcase Start Exhaust	Bin200	0.012352
1	Total Gaseous Hydrocarbons	17	Crankcase Extended Idle Exhaust	Bin1	0.9184
1	Total Gaseous Hydrocarbons	17	Crankcase Extended Idle Exhaust	Bin200	0.9184
1	Total Gaseous Hydrocarbons	90	Extended Idle Exhaust	Bin1	45.92
1	Total Gaseous Hydrocarbons	90	Extended Idle Exhaust	Bin200	45.92
2	Carbon Monoxide (CO)	2	Start Exhaust	Bin1	10.2629
2	Carbon Monoxide (CO)	2	Start Exhaust	Bin200	10.2629
2	Carbon Monoxide (CO)	16	Crankcase Start Exhaust	Bin1	0.030789
2	Carbon Monoxide (CO)	16	Crankcase Start Exhaust	Bin200	0.030789
2	Carbon Monoxide (CO)	17	Crankcase Extended Idle Exhaust	Bin1	0.223859
2	Carbon Monoxide (CO)	17	Crankcase Extended Idle Exhaust	Bin200	0.223859
2	Carbon Monoxide (CO)	90	Extended Idle Exhaust	Bin1	74.6199
2	Carbon Monoxide (CO)	90	Extended Idle Exhaust	Bin200	74.6199
3	Oxides of Nitrogen (NOx)	2	Start Exhaust	Bin1	0
3	Oxides of Nitrogen (NOx)	2	Start Exhaust	Bin200	0
3	Oxides of Nitrogen (NOx)	16	Crankcase Start Exhaust	Bin1	0
3	Oxides of Nitrogen (NOx)	16	Crankcase Start Exhaust	Bin200	0
3	Oxides of Nitrogen (NOx)	17	Crankcase Extended Idle Exhaust	Bin1	0.108101
3	Oxides of Nitrogen (NOx)	17	Crankcase Extended Idle Exhaust	Bin200	0.108101
3	Oxides of Nitrogen (NOx)	90	Extended Idle Exhaust	Bin1	216.202
3	Oxides of Nitrogen (NOx)	90	Extended Idle Exhaust	Bin200	216.202
90	Atmospheric CO2	2	Start Exhaust	Bin1	0
90	Atmospheric CO2	2	Start Exhaust	Bin200	0
90	Atmospheric CO2	90	Extended Idle Exhaust	Bin1	0
90	Atmospheric CO2	90	Extended Idle Exhaust	Bin200	9066.28
91	Total Energy Consumption	2	Start Exhaust	Bin1	0
91	Total Energy Consumption	2	Start Exhaust	Bin200	0
91	Total Energy Consumption	90	Extended Idle Exhaust	Bin1	0
91	Total Energy Consumption	90	Extended Idle Exhaust	Bin200	123631
98	CO2 Equivalent	2	Start Exhaust	Bin1	0
98	CO2 Equivalent	2	Start Exhaust	Bin200	0
98	CO2 Equivalent	90	Extended Idle Exhaust	Bin1	0
98	CO2 Equivalent	90	Extended Idle Exhaust	Bin200	9066.28
100	Primary Exhaust PM10 - Total	2	Start Exhaust	Bin1	0

pollutantID	Pollutant Name	processID	Process Name	MOVESScenarioID	Emssion Rate (grams/hour)
100	Primary Exhaust PM10 - Total	2	Start Exhaust	Bin200	0
100	Primary Exhaust PM10 - Total	16	Crankcase Start Exhaust	Bin1	0
100	Primary Exhaust PM10 - Total	16	Crankcase Start Exhaust	Bin200	0
100	Primary Exhaust PM10 - Total	17	Crankcase Extended Idle Exhaust	Bin1	0.699572
100	Primary Exhaust PM10 - Total	17	Crankcase Extended Idle Exhaust	Bin200	0.700434
100	Primary Exhaust PM10 - Total	90	Extended Idle Exhaust	Bin1	3.49786
100	Primary Exhaust PM10 - Total	90	Extended Idle Exhaust	Bin200	3.5023
101	Primary PM10 - Organic Carbon	2	Start Exhaust	Bin1	0
101	Primary PM10 - Organic Carbon	2	Start Exhaust	Bin200	0
101	Primary PM10 - Organic Carbon	16	Crankcase Start Exhaust	Bin1	0
101	Primary PM10 - Organic Carbon	16	Crankcase Start Exhaust	Bin200	0
101	Primary PM10 - Organic Carbon	17	Crankcase Extended Idle Exhaust	Bin1	0.480447
101	Primary PM10 - Organic Carbon	17	Crankcase Extended Idle Exhaust	Bin200	0.480447
101	Primary PM10 - Organic Carbon	90	Extended Idle Exhaust	Bin1	2.40223
101	Primary PM10 - Organic Carbon	90	Extended Idle Exhaust	Bin200	2.40223
102	Primary PM10 - Elemental Carbon	2	Start Exhaust	Bin1	0
102	Primary PM10 - Elemental Carbon	2	Start Exhaust	Bin200	0
102	Primary PM10 - Elemental Carbon	16	Crankcase Start Exhaust	Bin1	0
102	Primary PM10 - Elemental Carbon	16	Crankcase Start Exhaust	Bin200	0
102	Primary PM10 - Elemental Carbon	17	Crankcase Extended Idle Exhaust	Bin1	0.219127
102	Primary PM10 - Elemental Carbon	17	Crankcase Extended Idle Exhaust	Bin200	0.219127
102	Primary PM10 - Elemental Carbon	90	Extended Idle Exhaust	Bin1	1.09563
102	Primary PM10 - Elemental Carbon	90	Extended Idle Exhaust	Bin200	1.09563
105	Primary PM10 - Sulfate Particulate	2	Start Exhaust	Bin1	0
105	Primary PM10 - Sulfate Particulate	2	Start Exhaust	Bin200	0
105	Primary PM10 - Sulfate Particulate	16	Crankcase Start Exhaust	Bin1	0
105	Primary PM10 - Sulfate Particulate	16	Crankcase Start Exhaust	Bin200	0
105	Primary PM10 - Sulfate Particulate	17	Crankcase Extended Idle Exhaust	Bin1	0
105	Primary PM10 - Sulfate Particulate	17	Crankcase Extended Idle Exhaust	Bin200	0.000861
105	Primary PM10 - Sulfate Particulate	90	Extended Idle Exhaust	Bin1	0
105	Primary PM10 - Sulfate Particulate	90	Extended Idle Exhaust	Bin200	0.004438
110	Primary Exhaust PM2.5 - Total	2	Start Exhaust	Bin1	0
110	Primary Exhaust PM2.5 - Total	2	Start Exhaust	Bin200	0
110	Primary Exhaust PM2.5 - Total	16	Crankcase Start Exhaust	Bin1	0
110	Primary Exhaust PM2.5 - Total	16	Crankcase Start Exhaust	Bin200	0
110	Primary Exhaust PM2.5 - Total	17	Crankcase Extended Idle Exhaust	Bin1	0.678603
110	Primary Exhaust PM2.5 - Total	17	Crankcase Extended Idle Exhaust	Bin200	0.679465
110	Primary Exhaust PM2.5 - Total	90	Extended Idle Exhaust	Bin1	3.39303
110	Primary Exhaust PM2.5 - Total	90	Extended Idle Exhaust	Bin200	3.39733
111	Primary PM2.5 - Organic Carbon	2	Start Exhaust	Bin1	0
111	Primary PM2.5 - Organic Carbon	2	Start Exhaust	Bin200	0

pollutantID	Pollutant Name	processID	Process Name	MOVESScenarioID	Emssion Rate (grams/hour)
111	Primary PM2.5 - Organic Carbon	16	Crankcase Start Exhaust	Bin1	0
111	Primary PM2.5 - Organic Carbon	16	Crankcase Start Exhaust	Bin200	0
111	Primary PM2.5 - Organic Carbon	17	Crankcase Extended Idle Exhaust	Bin1	0.466047
111	Primary PM2.5 - Organic Carbon	17	Crankcase Extended Idle Exhaust	Bin200	0.466047
111	Primary PM2.5 - Organic Carbon	90	Extended Idle Exhaust	Bin1	2.33023
111	Primary PM2.5 - Organic Carbon	90	Extended Idle Exhaust	Bin200	2.33023
112	Primary PM2.5 - Elemental Carbon	2	Start Exhaust	Bin1	0
112	Primary PM2.5 - Elemental Carbon	2	Start Exhaust	Bin200	0
112	Primary PM2.5 - Elemental Carbon	16	Crankcase Start Exhaust	Bin1	0
112	Primary PM2.5 - Elemental Carbon	16	Crankcase Start Exhaust	Bin200	0
112	Primary PM2.5 - Elemental Carbon	17	Crankcase Extended Idle Exhaust	Bin1	0.212558
112	Primary PM2.5 - Elemental Carbon	17	Crankcase Extended Idle Exhaust	Bin200	0.212558
112	Primary PM2.5 - Elemental Carbon	90	Extended Idle Exhaust	Bin1	1.06279
112	Primary PM2.5 - Elemental Carbon	90	Extended Idle Exhaust	Bin200	1.06279
115	Primary PM2.5 - Sulfate Particulate	2	Start Exhaust	Bin1	0
115	Primary PM2.5 - Sulfate Particulate	2	Start Exhaust	Bin200	0
115	Primary PM2.5 - Sulfate Particulate	16	Crankcase Start Exhaust	Bin1	0
115	Primary PM2.5 - Sulfate Particulate	16	Crankcase Start Exhaust	Bin200	0
115	Primary PM2.5 - Sulfate Particulate	17	Crankcase Extended Idle Exhaust	Bin1	0
115	Primary PM2.5 - Sulfate Particulate	17	Crankcase Extended Idle Exhaust	Bin200	0.000861
115	Primary PM2.5 - Sulfate Particulate	90	Extended Idle Exhaust	Bin1	0
115	Primary PM2.5 - Sulfate Particulate	90	Extended Idle Exhaust	Bin200	0.004305

APPENDIX D: MOVES PANEL SELECTION SCREENSHOTS

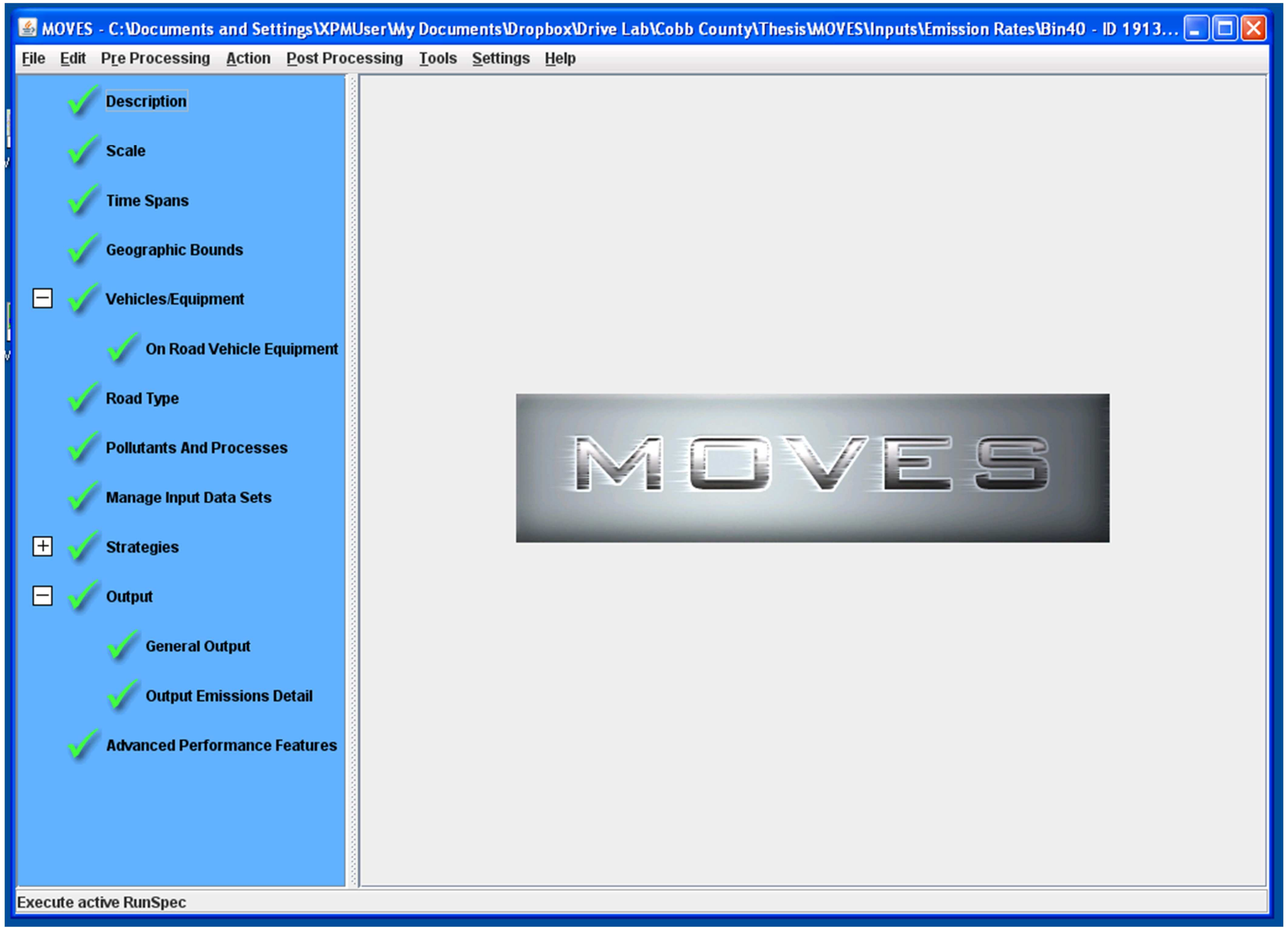

Figure D.1: MOVES Interface

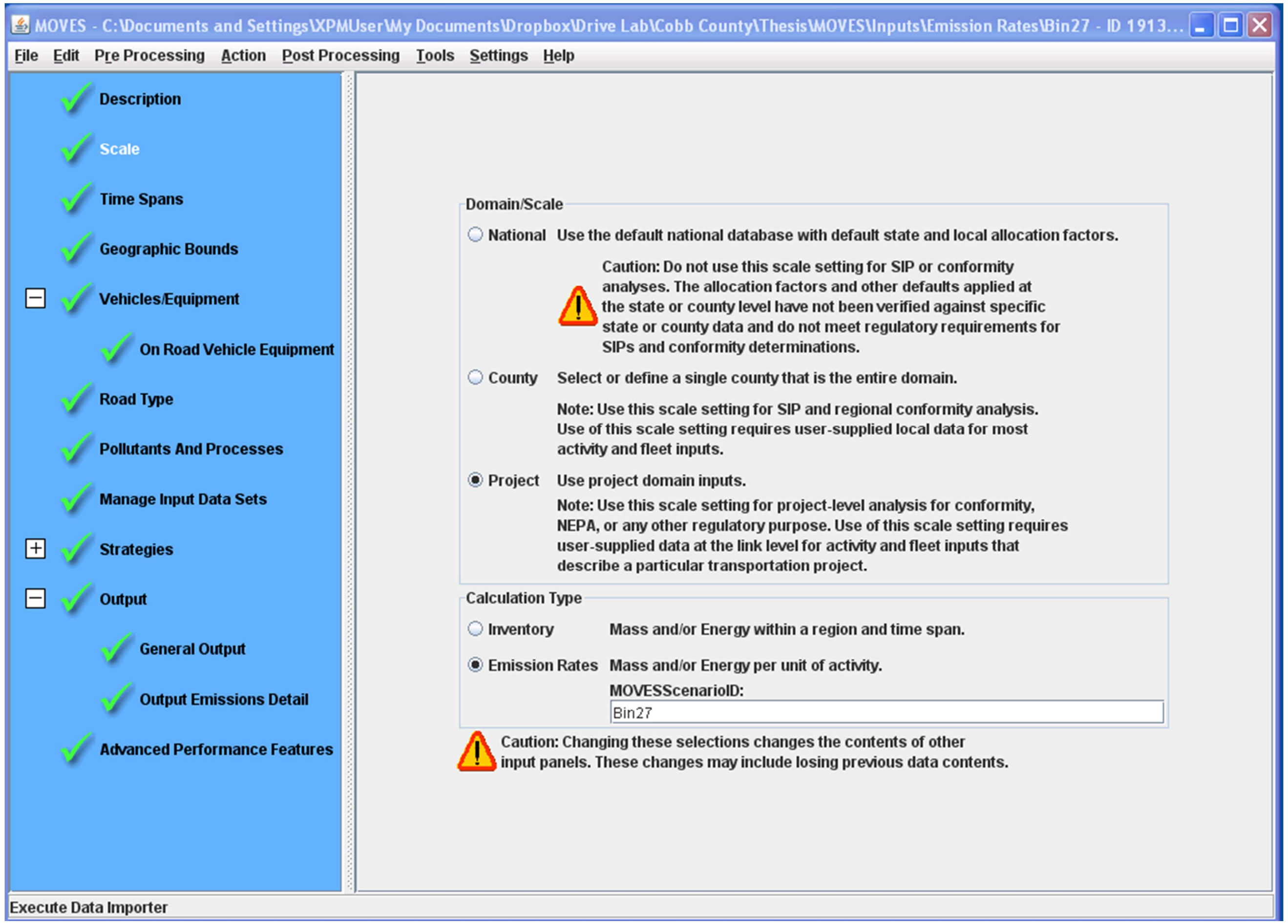

Figure D.2: MOVES Scale Panel

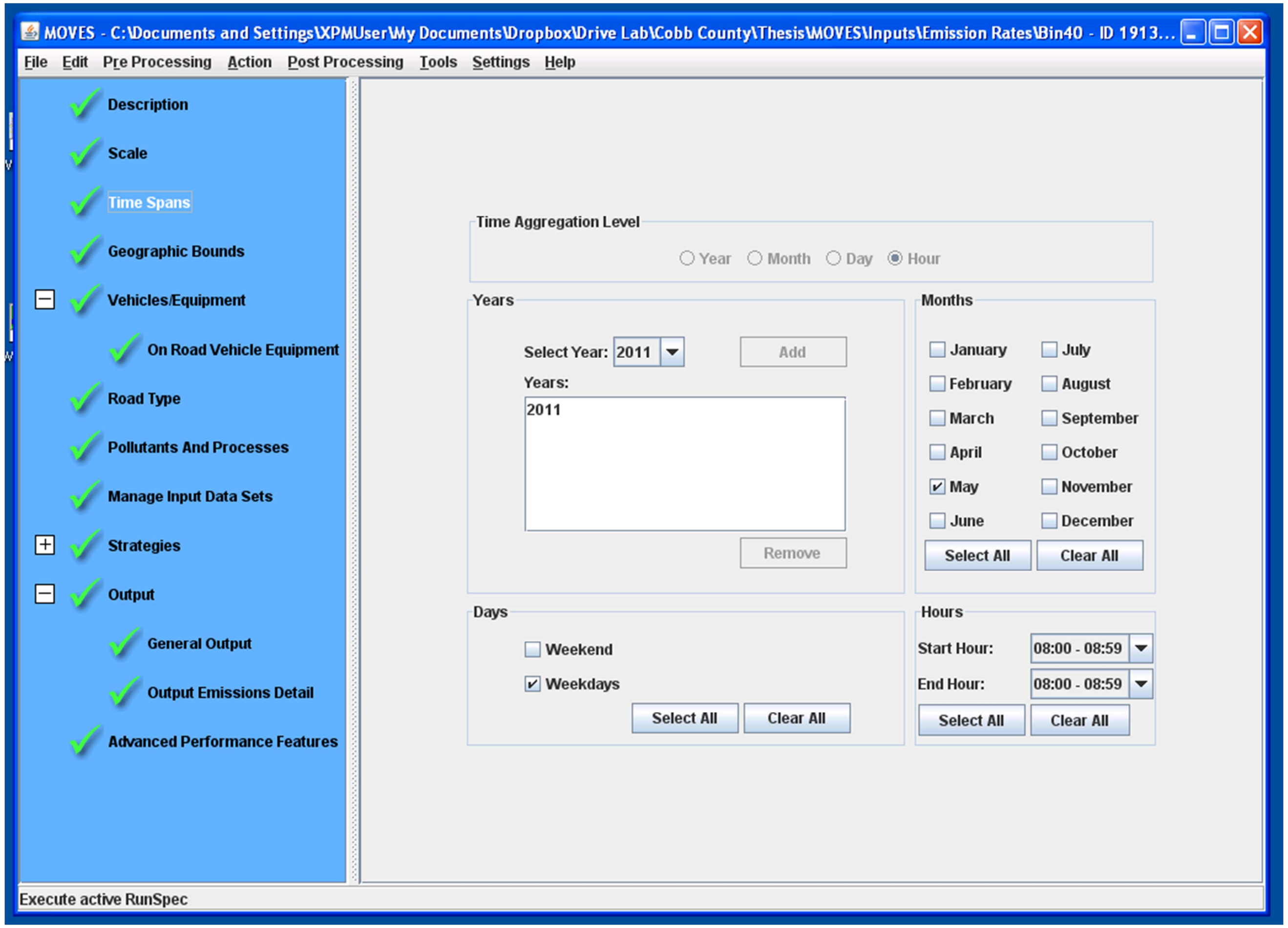

Figure D.3: MOVES Time Spans Panel

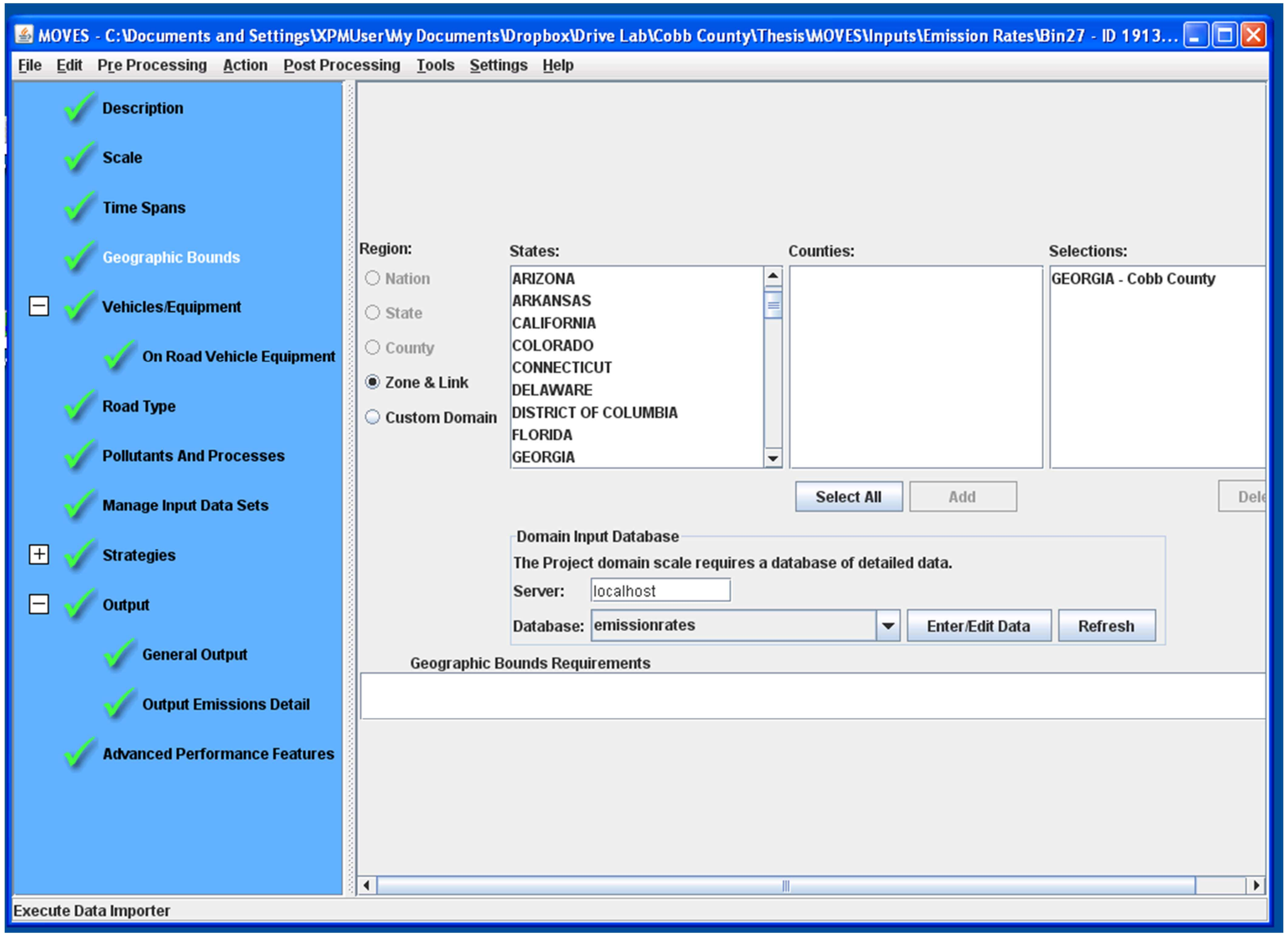

Figure D.4: MOVES Geographic Bounds Panel

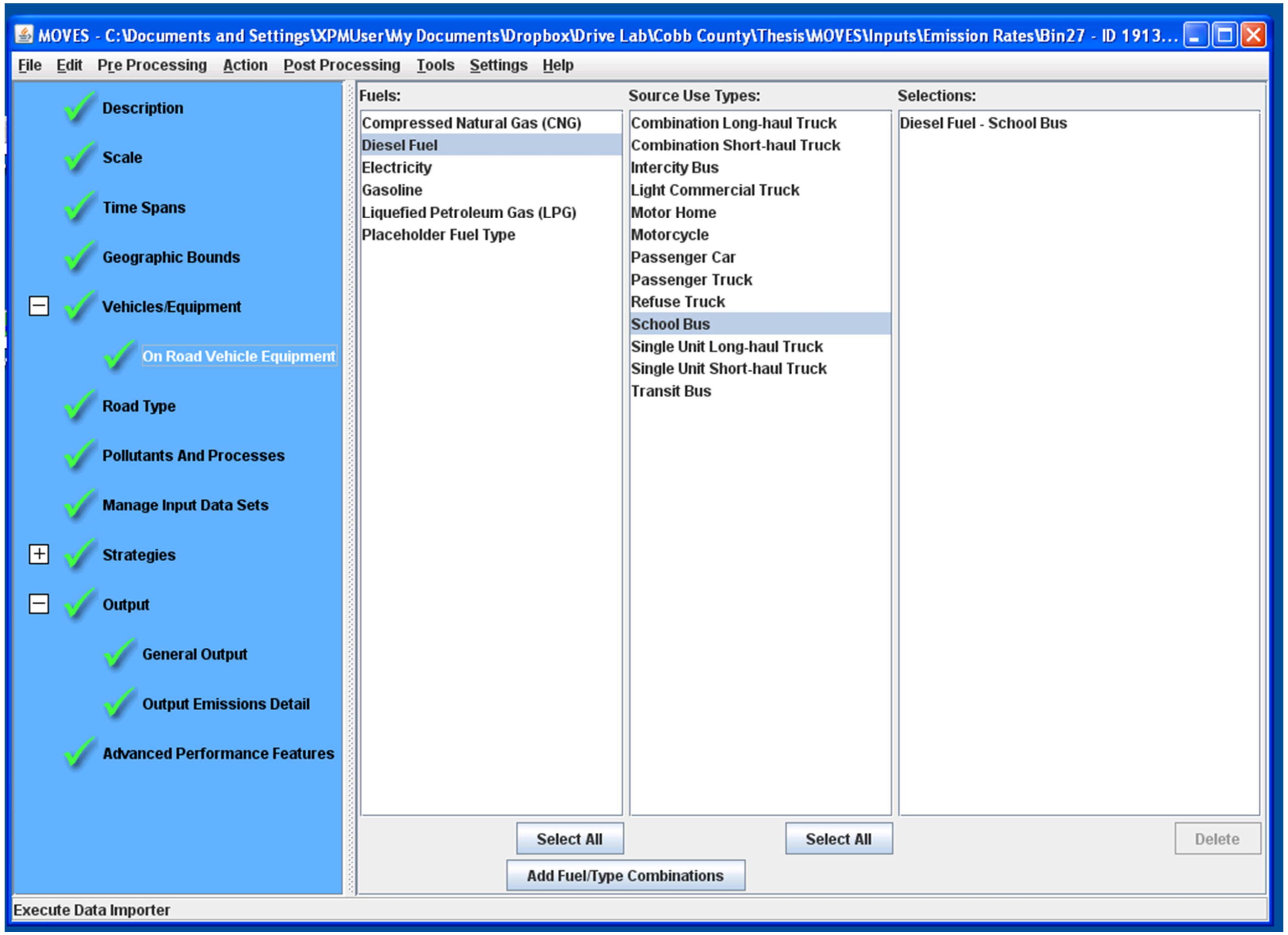

Figure D.5: MOVES On Road Vehicle Equipment Panel

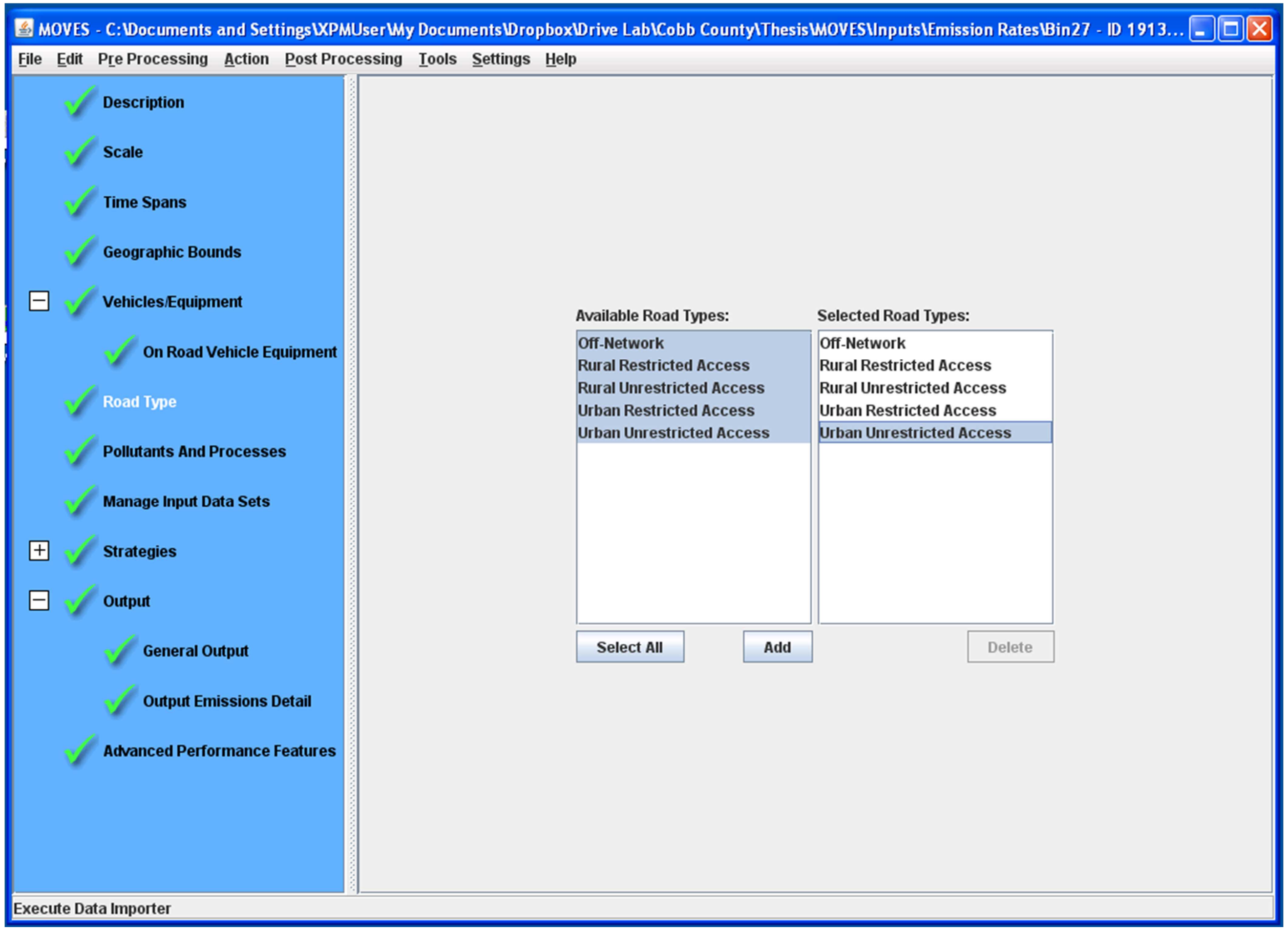

Figure D.6: MOVES Road Type Panel

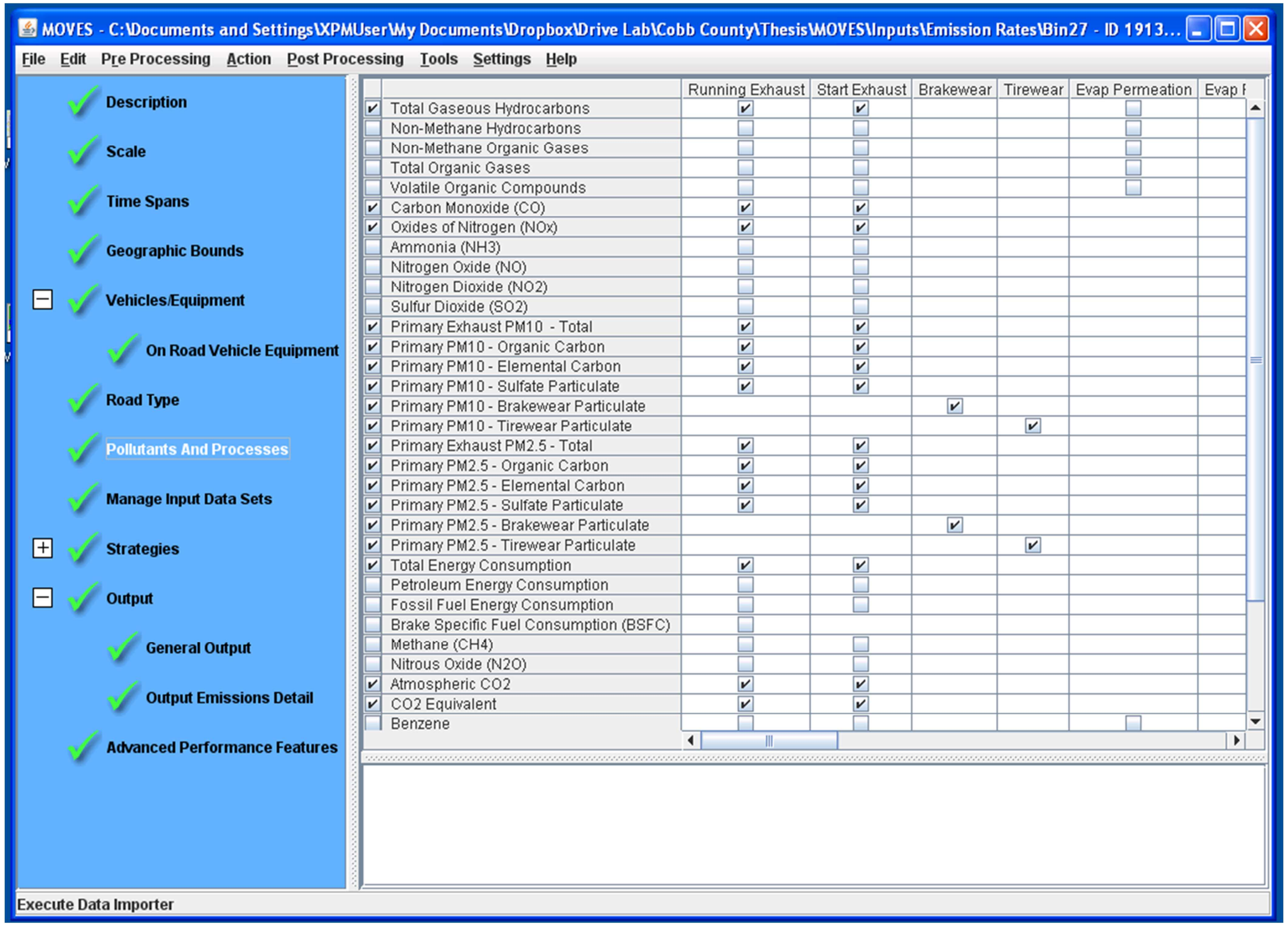

Figure D.7: MOVES Pollutants and Processes Panel

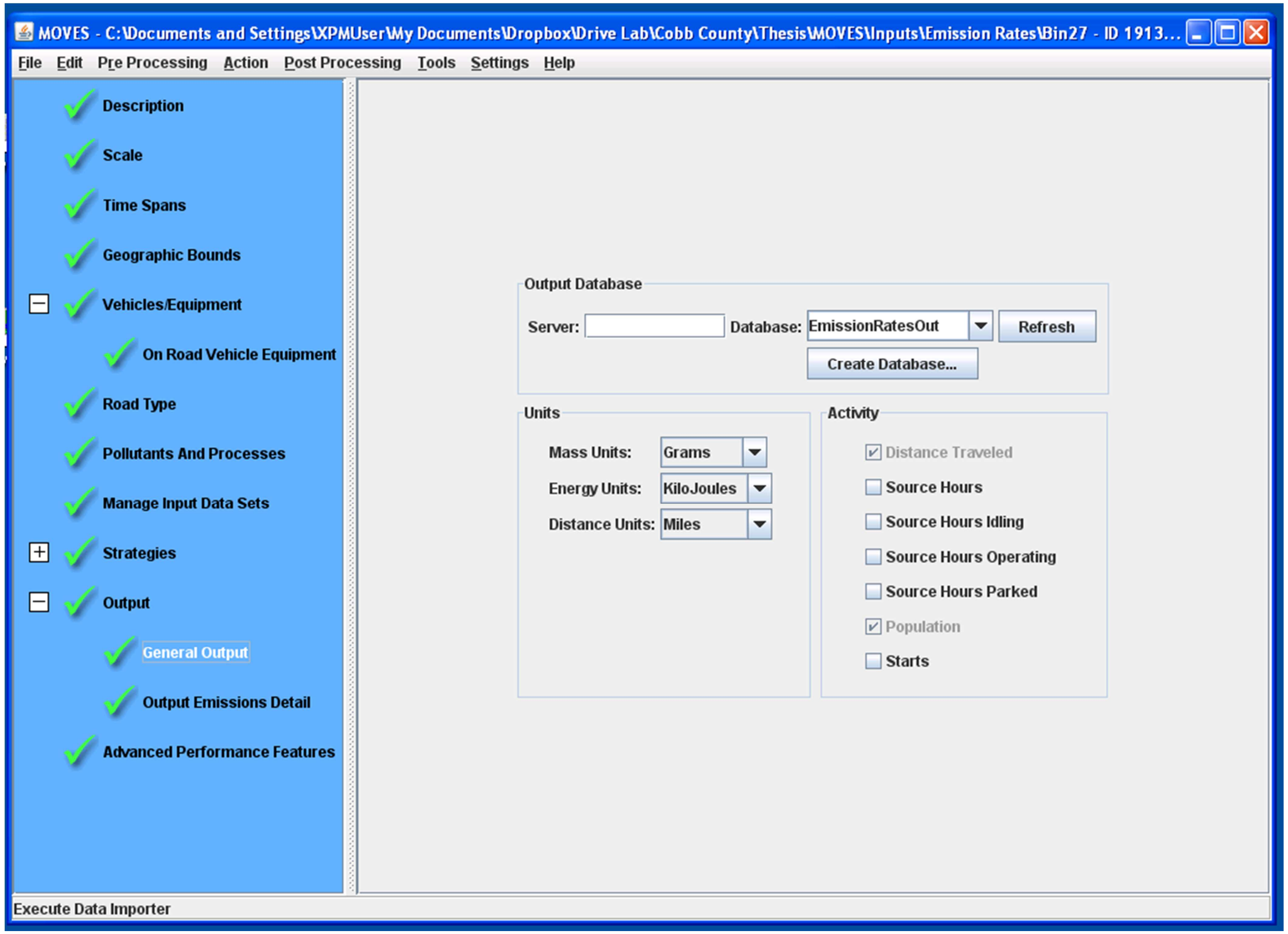

Figure D.8: MOVES General Output Panel

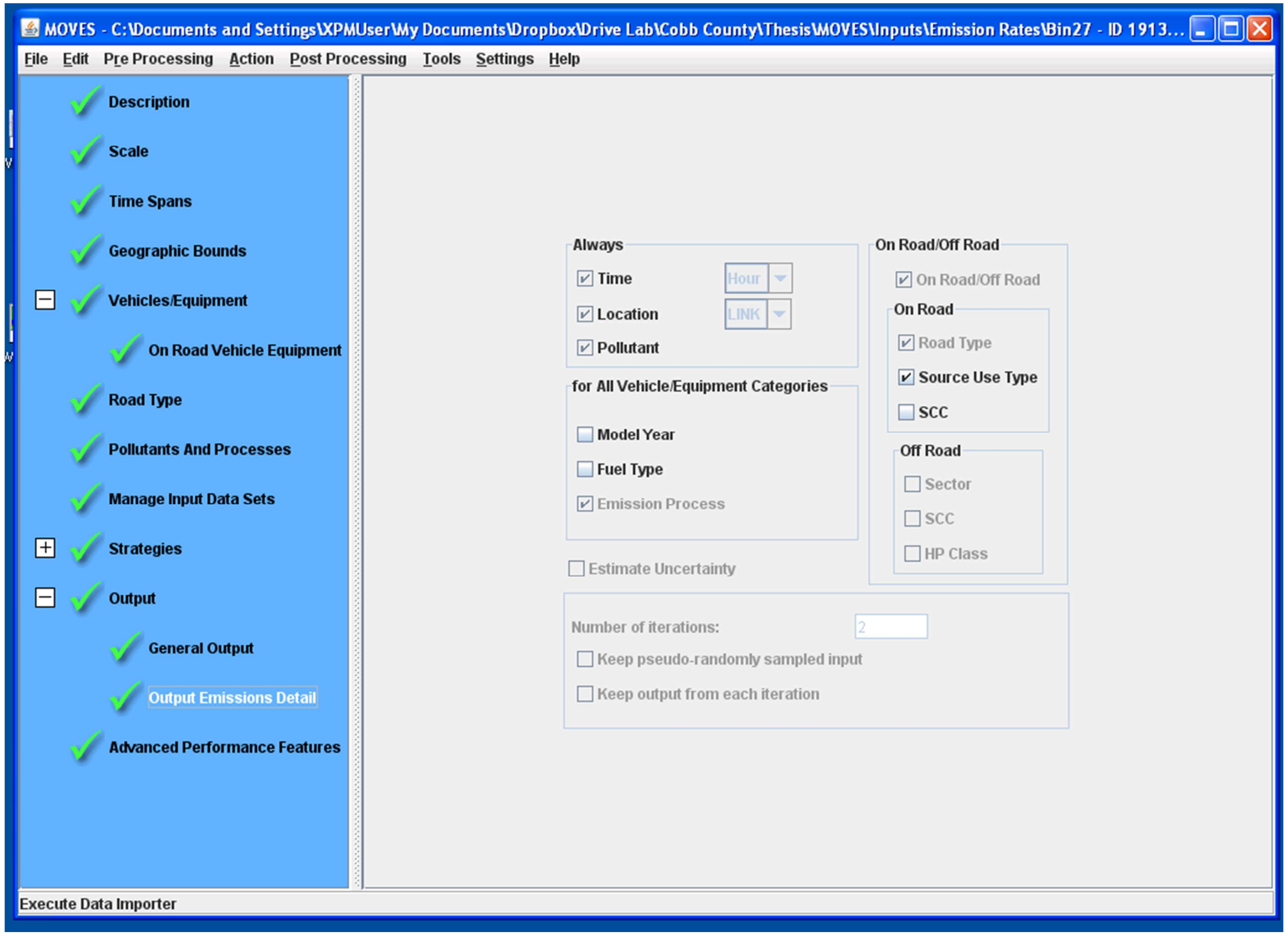

Figure D.9: MOVES Output Emissions Detail Panel

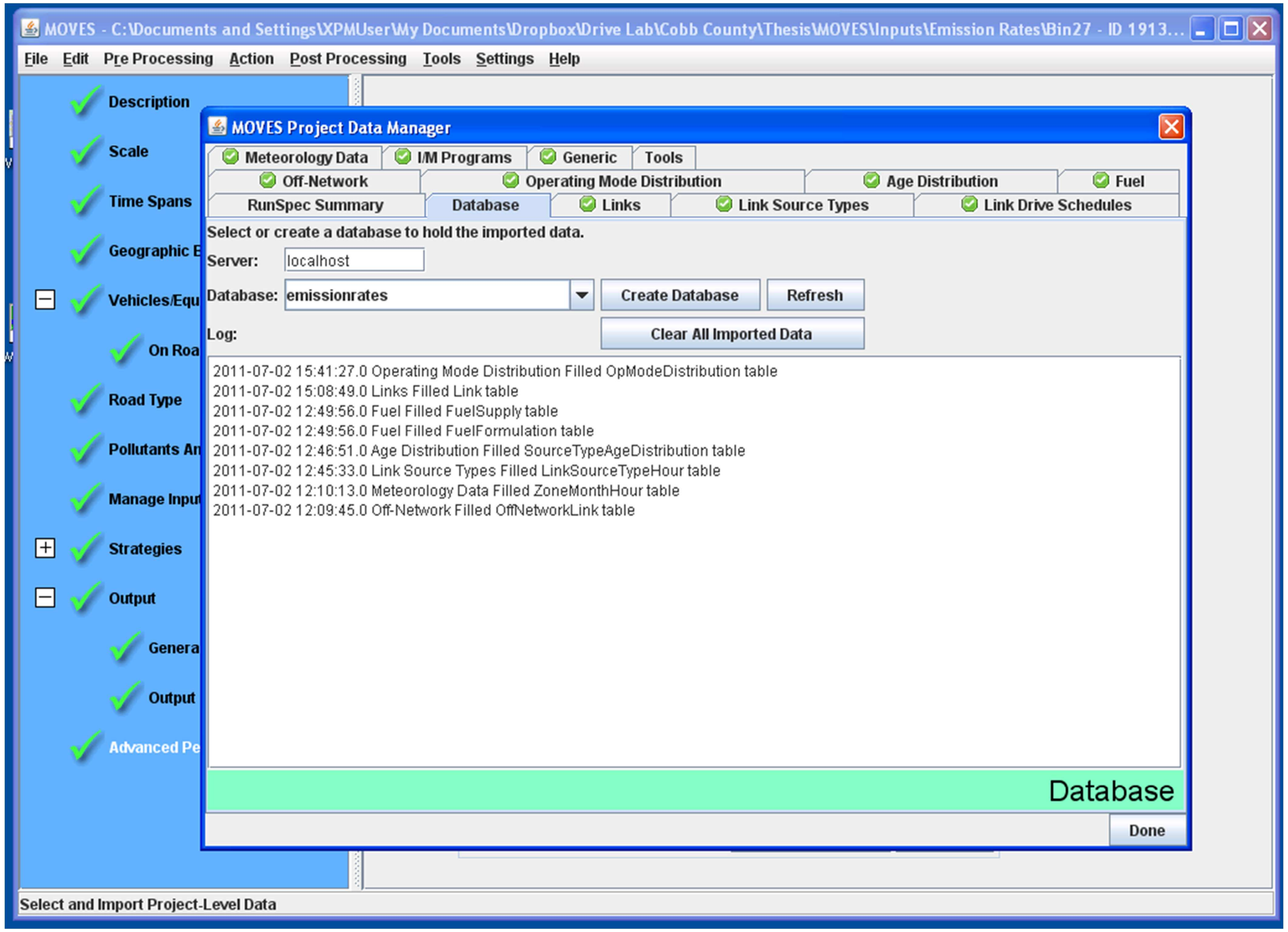

Figure D.10: MOVES Project Data Manager

APPENDIX E: EMISSION RATE GRAPHS

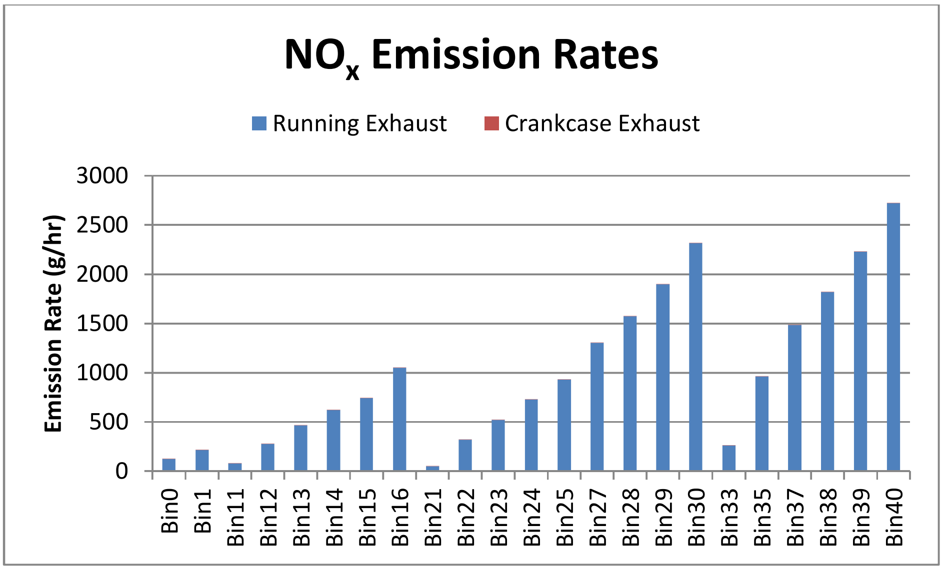

Figure E.1: NOx Emission Rates by Operating Mode Bin

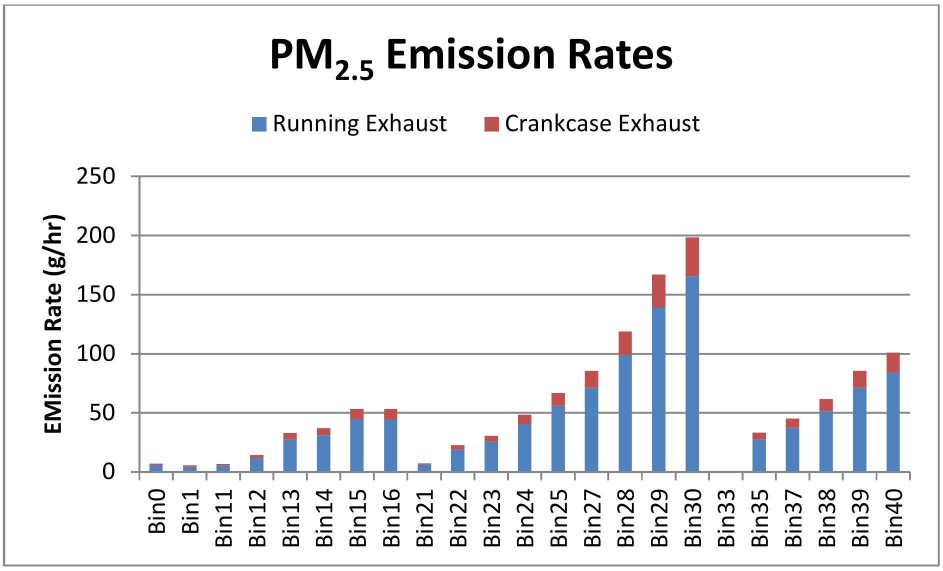

Figure E.2: PM2.5 Emission Rates by Operating Mode Bin

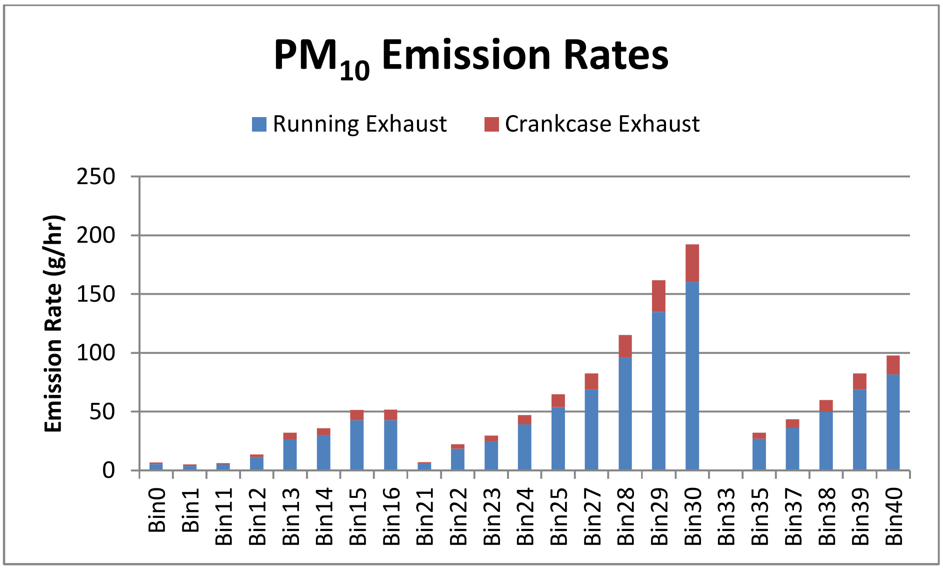

Figure E.3: PM10 Emission Rates by Operating Mode Bin

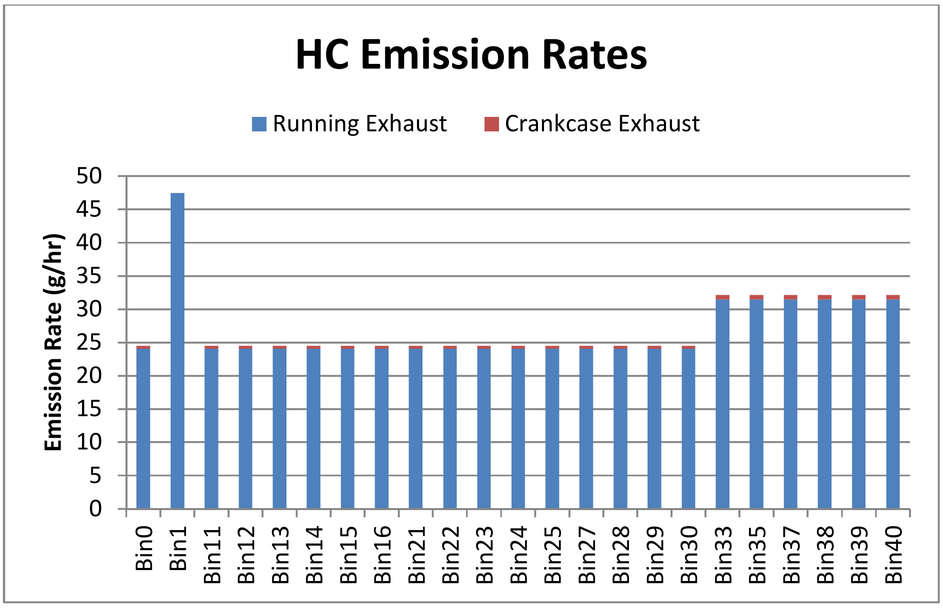

Figure E.4: HC Emission Rates by Operating Mode Bin

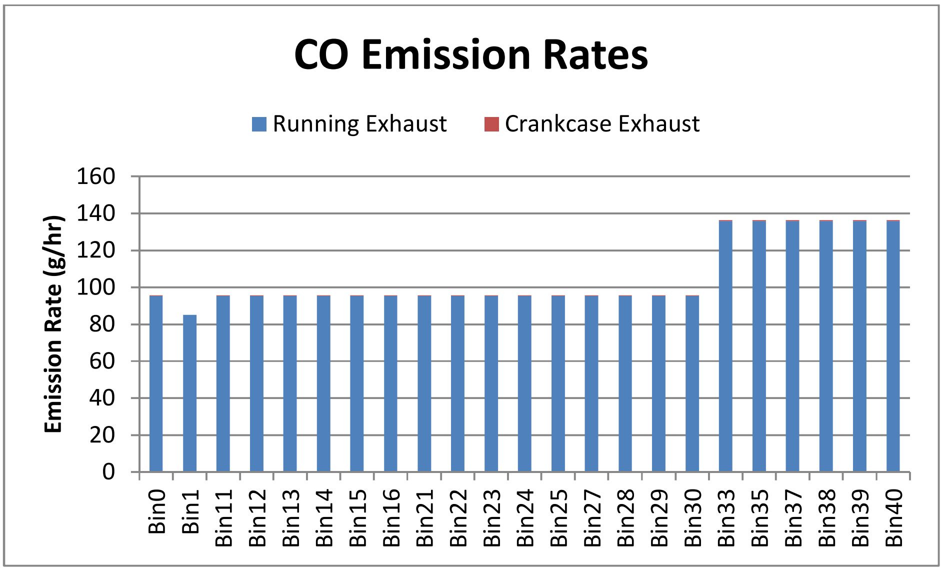

Figure E.5: CO Emission Rates by Operating Mode Bin

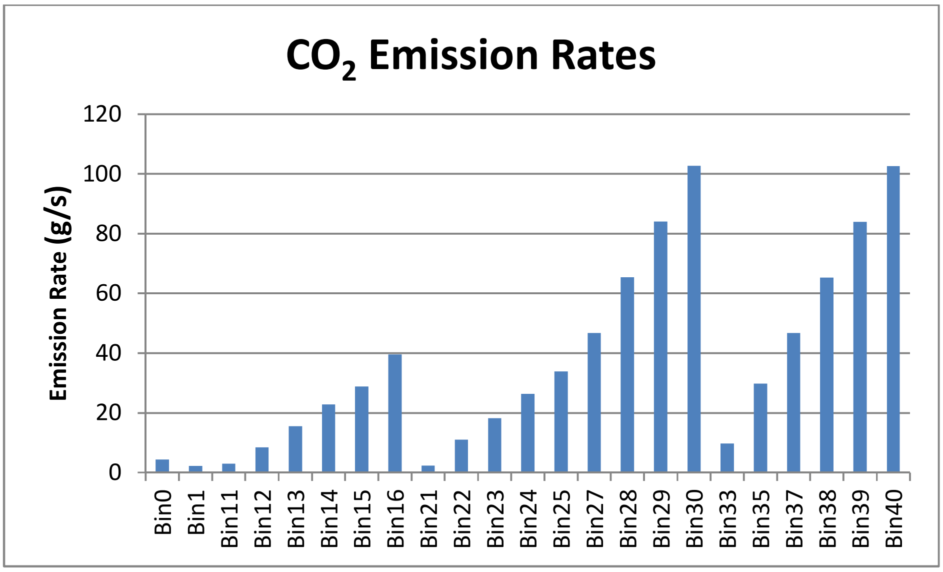

Figure E.6: CO2 Emission Rates by Operating Mode Bin

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