NONROAD MOBILE Emissions Modeling

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Paper proposed for presentation at
The Emission Inventory:
Planning for the Future
October 28-30, 1997
Research Triangle Park, North Carolina

ABSTRACT

This paper describes the EPA nonroad mobile source emissions model now under development. The NONROAD model, as it is called, will be released in a beta version in early 1998, and then in final version in late summer 1998. The current working version of the model estimates emissions from nonroad agricultural, construction, industrial, recreational marine, and lawn and garden equipment; emissions from commercial marine, locomotive, and aircraft equipment may be added before the final release of the model if resources are available. Engine types covered by the model include two- and four-stroke gasoline and diesel engines, and CNG/LPG engines. These engines are used in both rural and urban areas, and their operation can range from primarily steady-state (e.g., generators) to extremely transient (e.g., backhoes or other construction equipment). Modeling emissions from the nonroad sector is especially challenging because of difficulties in determining in-use population, activity, load, and emission rates. The in-use population for nonroad engines is difficult to determine because the equipment is not registered or permitted as it is for highway mobile or stationary sources. In this paper, the capabilities, structure, basic calculations, input data required, and output of the model will be described. The paper will also include a discussion of the current sources of in-use population estimates, equipment age distribution, emission factors, activity estimates, growth estimates, and geographic and temporal allocation factors.

INTRODUCTION

Air pollution in the United States results from the emission of a wide variety of manmade and natural pollutants such as volatile organic compounds (VOC) , nitrogen oxides (NO_x), air toxics, and particulate matter (PM). Under the Clean Air Act, the U.S. Environmental Protection Agency (EPA) is given specific responsibilities to reduce the emissions of pollutants from a range of sources in order to provide clean and healthy air in the United States.

Generally speaking, the EPA classifies anthropogenic (manmade) emissions into three broad categories, mobile, stationary (point), and area sources. Mobile source emissions (historically included in area source emissions) are further disaggregated into on-road (e.g., cars, trucks, and motorcycles) and nonroad emission categories. Because of the significant contribution of nonroad emission sources to the total mobile source emission inventory, it has become critical over the past several years for the EPA to provide state and local pollution control agencies with the ability to easily create and project accurate, reproducible inventories of nonroad emissions to satisfy the specific requirements of the Clean Air Act Amendments of 1990.

In a report issued by the EPA in 1991, the agency reported that nonroad vehicles and equipment were a significant source of VOC, NO_x , and PM emissions (1). The report showed that in some areas of the country, nonroad emissions contributed to as much as a third of the total mobile source NO_x and VOC inventory and over two-thirds of the mobile source PM inventory.

To assist states and local regulatory agencies in the creation of accurate nonroad emission inventories, the EPA is currently developing a national nonroad emissions model, referred to as NONROAD. The beta version of the nonroad emissions model, which will be released in early 1998, will predict emissions for all nonroad equipment categories and subcategories with the exception of locomotive and aircraft emissions; future model updates will include modules for estimating emissions from those sources if resources are available. The model estimates emissions for current years, and includes growth and scrappage functions to predict emissions for future years as well as to backcast emissions for past years.

Structurally, the model is made up of three specific components: a graphical user interface (GUI), which allows the user to easily input model parameters; the core model, which contains all computational algorithms; and a reporting utility for viewing and summarizing modeled emissions estimates.

The current schedule calls for the release of the beta version of the model in early 1998 for testing and peer review by air quality planning agencies and other interested parties, finalizing the model in mid-1998, and releasing the model in August 1998.

NONROAD MODEL DESCRIPTION

Equipment Types

The NONROAD model estimates emissions from a diverse collection of vehicles and equipment types in the following categories:

- airport ground support, such as terminal tractors;
- agricultural equipment, such as tractors, combines, and balers;
- construction equipment, such as graders and back hoes;

- industrial and commercial equipment, such as fork lifts and sweepers;
- recreational vehicles, such as all-terrain vehicles and off-road motorcycles;
- residential and commercial lawn and garden equipment, such as leaf and snow blowers;
- logging equipment, such as shredders and large chain saws;
- recreational marine vessels, such as power boats.
- underground mining equipment; and
- oil field equipment.

The model includes more than 80 basic and 260 specific types of nonroad equipment, and further stratifies equipment types by horsepower rating. Fuel types include gasoline, diesel, compressed nocturnal gas (CNG), and liquified petroleum gas 9LPG). The user has the option of estimating emissions for all source types, or for one or more selected main categories of nonroad equipment. The user can also specify all fuels or one or more specific fuel types. Furthermore, the user can select one or more specific types of nonroad equipment with a specified fuel type(s).

While the current working version of the model does not include emissions from aircraft, locomotive, or commercial marine equipment, these sources may be added before the final release if resources are available.

Pollutants Reported

The NONROAD model estimates emissions for six exhaust pollutants: hydrocarbons (HC), NO_X, carbon monoxide (CO), carbon dioxide (CO_2), sulfur oxides (SO_X), and PM. The user selects among five different types for reporting HC — as total hydrocarbons (THC), total organic gases (TOG), non-methane organic gases (NMOG), non-methane hydrocarbons (NMHC), or volatile organic compounds (VOC). Particulate matter can be reported as total PM, PM of 10µ or less (PM_{10}), or PM of 2.5µ or less ($PM_{2.5}$). The model also estimates emissions of non-exhaust HC for six modes — hot soak, diurnal, refueling, resting loss, running loss, and crankcase emissions.

Geographic and Temporal Coverage

In each run of the model, the user selects what geographic area(s) are top be included. At the broadest level, the model estimates national total emissions. More commonly users will specify emissions by state, or for one or more counties within a state. At the most detailed level, the user can estimate sub-county emissions; however, this is an advanced feature and the user must supply sub-county input data of the types described below. Thus the model is capable of estimating, in a single run, emissions for nonattainment areas which may consist of multiple counties or sub-counties in one or more states.

The NONROAD model can estimate current year emissions for the specified geographic area as well as project future year emissions and backcast past year emissions. In estimating future year projections and in backcasting, the model includes growth and scrappage rates for equipment in addition to a variety of control program options (discussed further below). The model can calculate emissions for a variety of time periods — an entire year, one of four seasons, or any particular month. Emissions for the period selected are estimated either for the total period or for a typical day (weekday or weekend) in that period.

Model Components

The NONROAD model consists of three separate components: (1) a graphical user interface written in Visual Basic, the core model written in Fortran, and a reporting utility written in Microsoft ACCESS.

When the model is released (in both the beta and final versions), an install utility will be supplied to easily install all three components of the model onto the user's machine.

The primary purpose of the interface is to provide the user with an easy method to specify the options for a model run. With simple Windows-type menus and pull-down screens, the user can quickly set up, execute, and view a modeling scenario. The user specifies modeling options by clicking on the choices desired in a series of screens; an example of the screen for specifying the period of interest is shown in Figure 1. Once the model options are specified, the user can then run the Fortran core model from within the interface, and then can move directly to the reporting utility to view and summarize the modeling results.

The core model of NONROAD, written in Fortran, contains all of the algorithms used by the model for calculating emissions estimates. The core model can be operated as a stand-alone application; however, as a stand-alone application it requires some basic knowledge of the DOS operating system. Also, note that while the user interface runs the core model for one specified set of conditions, it cannot run multiple runs in batch mode. However, multiple runs can be performed by creating and running a batch file in DOS or in a DOS window in a Windows 3.1 or 95 environment.

The reporting utility, written using Microsoft's ACCESS database software, is used to create standardized reports using output data generated in the core model. Like the graphical user interface, the reporting utility is a fully operational Windows program, with pull-down menus, designed as a separate module in order to take advantage of the many reporting and formatting options available when using a database application. Although the reporting utility is written in ACCESS, it is a stand-alone application, and you do not need to know how to use ACCESS to generate reports.

The reporting utility provides the user with seven types of standard reports:

- Emissions Totals by County
- Emissions Totals by Equipment Type
- Emissions Totals by Horsepower
- Emissions Totals by SCC (source category code)
- Emissions Totals by SCC and Horsepower
- Emissions Totals by Source Classification
- Population and Fuel Consumption by SCC

For most reports, emissions can be reported for either all counties or for a single, user-specified county. Reports that include emissions estimates by equipment types or by SCC are separated by major source classification (e.g., agricultural, lawn and garden), with subtotals provided for each classification. For those reports, equipment type descriptions are also included (e.g., 2-wheel tractors, asphalt pavers, etc.). Where appropriate, reports also include a grand total by pollutant.

In addition to generating and viewing standardized reports from single model runs, the reporting utility provides the user the ability to compare the results of two separate model runs. The current version of the reporting utility has standardized reports for comparing two model runs by

- Source Classification Code (SCC),
- Horsepower and SCC, and
- Population and Fuel.

For the comparison reports by SCC and horsepower by SCC, the report displays the results of the two model runs, and the absolute and percent difference between the two model. For the population and fuel comparison report, the report displays only the results of the two model runs side by side. The comparison reports are useful, for example, to compare emissions from present and future year projections, or to compare emissions with two different future year control programs.

Output Options

Output from the core model is an ASCII reporting file, which can be imported directly into the reporting utility by simply specifying the file name. The reporting facility can then be used to generate the standardized reports; users with ACCESS can generate their own reports or query the emissions estimates and other output from the model. The ASCII file can also easily be imported into an Excel or Lotus spreadsheet for those users who prefer spreadsheet application; in addition, these spreadsheet applications can generate graphs of model output.

The current version of the reporting utility includes reports only. If resources are available, the stand-alone reporting utility may be enhanced before its final release to include standardized graphical presentation of model output. However, the reporting utility has a feature that allows users to easily output an Excel file of data in a tabulated report; Excel can then be used to graph the tabled results.

Lastly, the user also has the option to generate an Emission Pre-Processor System 2 (EPS-2) input file. EPS-2 is a program, available on EPA's Web site or bulletin board, that can take the county-level output from the NONROAD core model and create gridded emissions files ready for input to the Urban Airshed Model (UAM), a photochemical grid model.

Computer Requirements

Minimum hardware system requirements for running the three NONROAD model components are a 486 with 16 megabytes of RAM. The core model, however, will run separately with 8 megabytes RAM. The three model components will run under either Windows 3.1 or Windows 95; the core model alone can be run under DOS. As the collection of programs and data files for the NONROAD model is quite large, approximately 30 megabytes, EPA will likely release the model and all of the input data files on CD-ROM; thus users must have a CD-ROM on their machine or accessible through a local network.

The disk space required for the NONROAD model depends on where the user elects to store the default data files supplied with the model. During the installation process, the user is prompted as to whether the default data files should be left on the CD-ROM or copied to the user's computer. If the user elects to leave the data files on the CD-ROM, the NONROAD model will require approximately 10 megabytes of disk space.

Documentation

Accompanying the beta and final releases of the NONROAD model will be an extensive User's Guide. The User's Guide describes in step-by-step detail the use and operation of the user interface, the core model, and the reporting utility. A large number of screen captures are included to clearly assist the user in specifying modeling options in the graphical user interface, as well as reporting options in the reporting utility. Throughout the User's Guide, helpful tips and notes are highlighted in text boxes.

EPA's Office of Mobile Sources will also be preparing a technical document that will be released with the final version of the model. This document will describe in detail all of the calculations

performed by the model. It will also document and describe all sources of data for model input files discussed below. A Programmer's Guide has also been prepared for assisting in understanding the inner workings of the model and preparing future updates to the model.

MODEL INPUTS

The NONROAD model estimates emissions for each specific type on nonroad equipment by multiplying the following estimates:

- Equipment population for base year (or base year population grown to a future year), distributed by age, power, fuel type, and application;
- Average load factor expressed as average fraction of available power ;
- Activity in hours of use per year; and
- Emission factor with deterioration and/or new standards.

The emissions are then temporally and geographically allocated using appropriate allocation factors.

There are several input files that provide necessary information to calculate and allocate these emissions estimates. These input files correspond to the basic data needed to provide the calculations: emission factors, base year equipment population, activity, load factor, average lifetime, scrappage function, growth estimates, and geographic and temporal allocation. The EPA will provide default values for all input files. The user can replace the default data files when better information becomes available, either from EPA for national defaults or from local sources for locality-specific data. The input files are also modified to test control strategies.

The EPA expects that users will change some input files, but expect that others will be adjusted only by the EPA. For instance, local users are less likely to alter the emission factors because new emission factor data for nonroad equipment are generally expensive to obtain. Conversely, local users are likely to change the geographic allocation of state equipment populations to the county level because of the availability of better local information.

What follows is a description of the most likely sources of default input data for the first release of EPA's NONROAD emissions model. Given that the model will not be released until later in 1998, and that an extensive review process will precede the release, these data sources are likely to change from what is described below.

Emission Factors

In contrast to highway vehicles, emission factors take the form of emission per work unit because nonroad engines primarily do work instead of traveling distance. EPA plans to provide estimates of total hydrocarbon (THC), carbon monoxide (CO), nitrogen oxides (NOx), particulate matter (PM), sulfur oxides (SO2), and fuel consumption. Each of these estimates requires an emission factor for each type of equipment.

The emission factors are generated primarily using a prescribed engine duty cycle. In most cases, engine data are produced using a set of steady-state modes which are time-weighted to represent in-use conditions. The emission factors in the current (prerelease) version of the model are those detailed in

EPA's Nonroad Engine and Vehicle Study (NEVES) (1). These emission factors are being reconsidered in light of new data generated since the time of the study.

Coupled with emission factors is the ability to distinguish between technology types in each engine application and power level grouping. Currently there are no technology types identified, but with the advent of new emission standards, some may be projected for future model years.

Inherent in the emission factors determination is an estimate of emissions deterioration. Deterioration for spark-ignition engines is derived from work completed in support of EPA's rulemaking for the less than 19 kW spark-ignition engines (6). Deterioration for diesel engines is derived from the MOBILE5a model (7).

Base Year Equipment Population

The base year equipment population is estimated by Power Systems Research (PSR) for each state. This firm estimates equipment population by tracking sales, manufacturers' estimates of engine life, usage, and other variables; and verifies estimates with detailed equipment population surveys. This equipment inventory is broken into several nonroad categories and several power levels. This allows for the appropriate geographic allocation and the implementation of new emission standards.

Unlike highway vehicle estimates, there is no registration data base for nonroad equipment. PSR estimates are therefore based on correlations and surveys developed over a number of years.

Activity

From their extensive surveys of equipment, PSR also estimates average activity in hours per year by equipment type. These equipment types are unique to the EPA definition of application types as listed in the SCC definitions.

Future studies may seek to verify the PSR estimate or gather more specific regional information. This type of information may be readily available for the larger engines because of the widespread use of hour meters like the Hobbs meter which can be tracked throughout a season or year.

Load Factor

The load factor is the fraction of available power used on average by nonroad engines. This is assumed to be specific to the application regardless of the engine used. The average load factor for each application was estimated by PSR based on their survey information.

Future work may involve surveying equipment usage in hours and fuel consumed during seasonal or yearly time frames. Each load factor would then be calculated as a fraction of maximum fuel consumption for that engine.

Average Life of the Engine

While the PSR estimates of equipment population also include information on expected life of engines, these are specific to the engine model employed. Given the overwhelming complexity and variety of engines used in the field, it is beyond the scope of this model to track every model of engine. Therefore, general average lifetimes are used in this model (2). These lifetimes were developed for the California Air Resources Board off highway emissions model (not yet publicly available).

It may be possible to track one or several engines throughout their lifetime to verify this estimate. However, with the wide variety of engine models and makes in use, such a study would require a large number of engines to be tracked to be certain that a calculated average value was appropriate.

Scrappage Function

The scrappage function is the expected survival rate of new engines as they age. In the current version, this scrappage function was derived from a normal distribution of age when scrapped centered around the average life of the engine. This distribution, shown in Figure 2, was derived from the PSR estimate that a normal distribution with a standard deviation of 2.3 in terms of engine hours at full load was the most representative function of age distribution.

Other possibilities for a scrappage function that could be used are the Weibull function which has been used to describe engine life (3). Like the normal distribution, the Weibull distribution is a generic two-parameter equation describing survival fractions by age or use. Note that by default the scrappage function in Figure 2 is used for all equipment types; the user can optionally provide an alternative default scrappage function for all equipment types, or alternative functions for specific equipment types only.

Growth Estimate

The growth estimate currently follows the generally accepted practice of using the Bureau of Economic Analysis (BEA) prediction of economic growth associated with the primary use of a given application. These growth factors are determined for each state individually using Gross State Product ($GSP) for specific sectors of the economy. Table 1 shows the association between the equipment application types and the BEA growth indicator.

Geographic Allocation

The allocation of state equipment population to the county level is a generic approach using County Business Patterns from the US Census Bureau (4). Like the growth indicator, economic indicators are associated with equipment applications to apportion a state population to the county level. This association is shown in Table 2.

Because general classifications are used, the possibility exists that unreasonable results for unique equipment applications may be misapplied. The user may use alternative allocations if more accurate information is available.

Temporal Allocation

The temporal allocation for month and day of the week were derived from CARB and NEVES (1) (2). These allocations seek to more appropriately scale yearly emissions for obviously seasonal activity and weekday or weekend day usage. Hourly emission estimates were not attempted for lack of a reasonable method for determining such allocations.

Table 1. Bureau of Economic Analysis (BEA) indicators used to project nonroad equipment population growth.

Equipment Application	BEA Economic Indicator
Recreational and Lawn & Garden	Human Population
Agricultural	$GSP Farm
Construction	$GSP Construction
Industrial and Commercial	$GSP Manufacturing
Logging	$GSP Lumber and Wood
Airport Service Equipment	$GSP Transportation by Air
Railway Maintenance	$GSP Transportation by Rail
Mining	$GSP Mining
Oil Field Equipment	$GSP Oil & Gas

Table 2. Economic indicators from U.S Census County Business Pattern data used to allocate state equipment population to the county level.

Equipment Application	County Business Pattern Indicator
Recreational	Motorcycle Dealerships (SIC-557) or Automotive Dealers and Service Station employees (SIC-55) if SIC-557 is unavailable
Lawn & Garden	Single family housing units (SFHU) for residential. Landscape and Horticultural Services employees (SIC-78) for commercial
Agricultural	Agricultural Services employees (SIC-07) adjusted to exclude Landscape and Horticultural Services employees (SIC-78)
Construction	Construction employees (SIC-15)
Industrial	Manufacturing employees (SIC-20)
Commercial	Wholesale establishments (SIC-50)
Logging	Lumber and Wood Products employees (SIC-24)
Recreational Marine	Ratio of county water surface area to total state water surface area. Water from large bodies of water included up to 1 mile offshore.
Airport Service Equipment	
Railway Maintenance	
Mining	
Oil Field Equipment	

Figure 1. Example screen for choosing NONROAD modeling options with the graphical user interface.

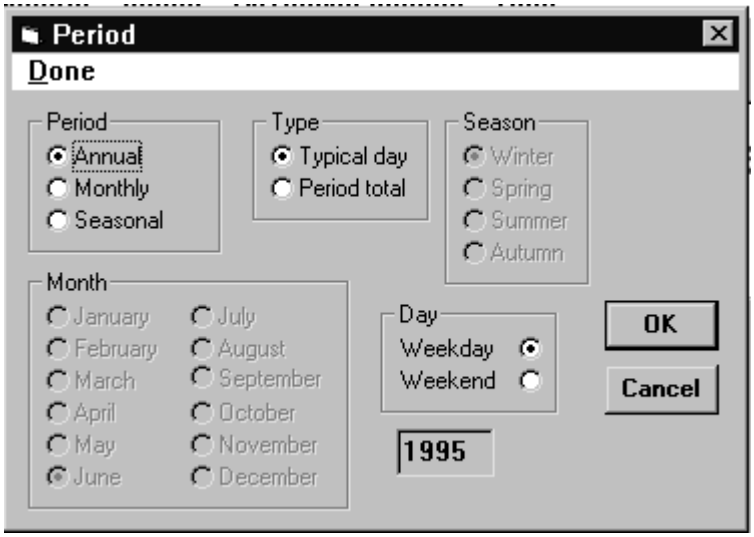
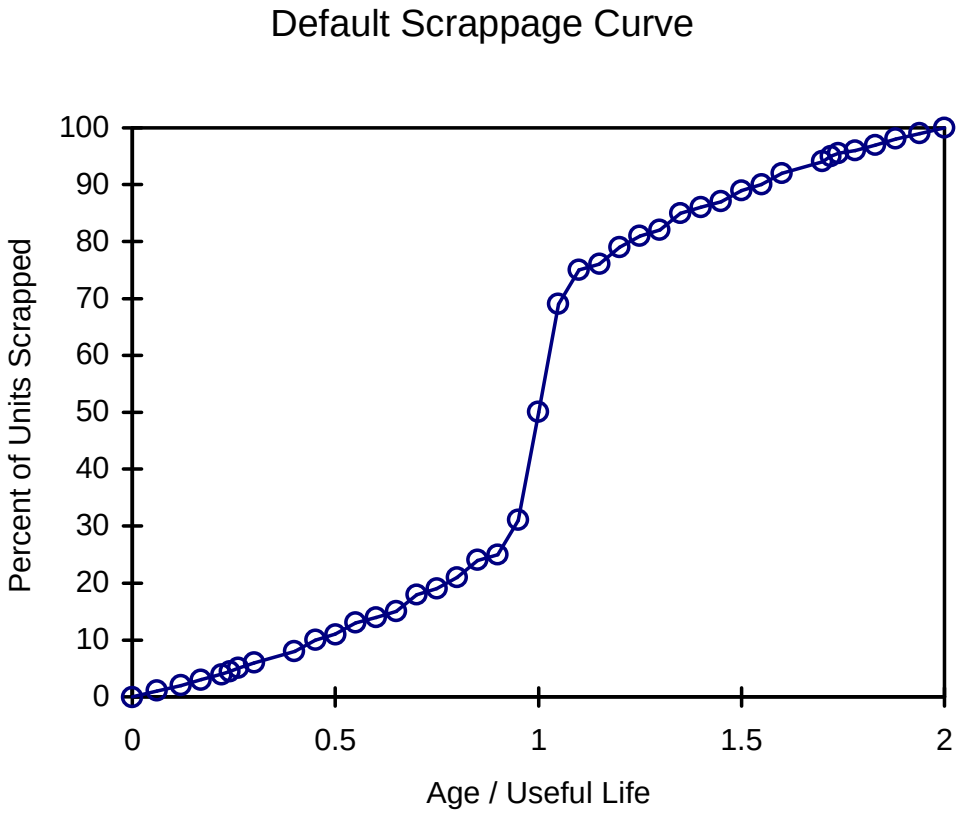


Figure 2. The default scrappage curve relating percent of units still in service to equipment age.



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KEY WORDS

emissions modeling, mobile source emissions, nonroad equipment