Overview: OFFROAD Model

PROGRAM STRUCTURE

The primary emphasis in designing OFFROAD was to provide an overall structure to incorporate the various aspects of off-road source emissions modeling, such as the effects of various adopted and proposed regulations, technology types, and seasonal conditions on emissions. This overall structure is illustrated in Figure 1. Fundamentally, the population, activity, and emission factors are still combined to yield the annual equipment emissions by county, air basin, or state. However, spatial and temporal features have been incorporated, making the new model more accurate in its depiction of emissions.

OFFROAD consists of three main modules: population, activity, and emissions factor. The 2000 base year equipment population is adjusted for growth and scrappage, producing model-year specific population distributions for specified calendar years from 1970 through 2040. The statewide population is allocated to each geographic region and reflects seasonal operating patterns. The base emission factors are corrected for in-use and ambient conditions. The annual equipment emissions are adjusted for ambient conditions. Emission inventories are produced for each county, air basin or district by fuel type (e.g., gasoline, diesel, compressed natural gas, etc.), engine type (e.g., two-stroke vs. four-stroke), equipment category, and horsepower group.

The output tables of OFFROAD have a standard layout that displays activity information and emission data. The activity table includes information regarding the population, use hours per day, starts per day, and gallons of fuel consumed per day. Criteria and toxic pollutants are reported for both exhaust and evaporative emission processes. While the output tables aggregate the information by equipment category for the state, the model can also produce more distinct information such as emission estimates of certain equipment type within a county and a 'by model year' option is also available.

METHODOLOGY

OFFROAD generates emission inventories by equipment type, accounting for age and for a given calendar year. The emissions inventory is calculated by the following equation:

Emissions in tons/day = EF * Pop * AvgHp * Load * Activity

Where:

AvgHp = Maximum rated average horsepower
Load = Load factor
Activity = Annual activity in hours per year (hr/yr)
EF = Emission factor in grams per horsepower-hour (g/bhp-hr)
Pop = Population

Categories and Equipment Types

There are 94 equipment types aggregated into 17 categories as listed in Table 1. The last update of the data driving the population, activity, and emissions modules is also listed. Emission inventories for ocean-going vessels, commercial harbor craft, locomotives, agricultural irrigation engines, and gas cans are developed in other stand alone models. Aircraft emissions are currently provided by the local air districts.

In general, the 17 categories include all equipment types used for a similar purpose or industry. The equipment types are further divided by fuel, engine type, horsepower group, preempted or non-preempted status, commercial or residential use, and portable or non-portable designation to better characterize emissions. The fuel and engine types represent a composite of technology types grouped as gasoline 2-stroke (G2), gasoline 4-stroke (G4), compressed natural gas or liquid petroleum gas (CNG/LPG), and diesel (D). The horsepower group cut points are 2, 5, 15, 25, 50, 120, 175, 250, 500, 750, 1000, and greater than 1000 hp. The preempted status is defined according to the Federal Clean Air Act where emissions from certain equipment types can only be regulated by the U. S. EPA and are, therefore, preempted from State regulations. The commercial or residential distinctions are primarily for lawn and garden equipment. The portable designation is applied to equipment types where a fraction is subject to the voluntary Portable Equipment Registration Program.

Population Module

This module contains growth factors and scrappage curves that are used to derive an equipment-specific model year population distribution for specified calendar years from 1970 through 2040. The statewide equipment population was obtained through various industry and government agency sources and was divided at the air basin and county level using activity indicators that reflect their usage in those areas.

Growth and Scrappage

The growth factors are based on socioeconomic indicators such as housing units and manufacturing employment by category, by county, and with respect to the 1990 base year sales. Scrappage is a static function of equipment age and use which varies by engine type and horsepower group. For all equipment types, except lawn and garden equipment and recreational vehicles, useful life represented in years is driven by the life of the engine. For lawn and garden equipment and recreational vehicles the useful life is determined by the life of the equipment. The useful life represents its median and relates to twice as many model years. For example, equipment having a median useful life of 32 years would span 64 model years in a given calendar year. Therefore, the baseline model year distribution is also dependent on the useful life of the equipment. In an effort to consistently update the OFFROAD model to the 2000 base year, the 1990 model year distribution was extrapolated in conjunction with category-specific growth factors.

Activity Module

This module contains information such as annual average use hours, load factor, brake-specific fuel consumption, and starts per year for each equipment type by fuel, engine type, and horsepower group. The activity information reflects seasonal and temporal conditions, as described below. Fuel consumption is also estimated for each equipment type using a carbon balance methodology.

Seasonal and Temporal Parameters

The equipment types from diverse industries such as agriculture, construction, and recreation, are included in the OFFROAD model, and their usage patterns are not identical. These seasonal and temporal influences are resolved by monthly, weekly, and daily use patterns for each type of equipment.

Most of the categories (construction, industrial, light commercial, and airport ground service equipment) have uniform activity throughout the year. Recreational vehicles, lawn and garden, and farm equipment display various seasonal use patterns. Equipment types within a category have the same monthly use pattern except for snowmobiles, snow blowers, chain saws (<=5 HP), and tillers. Although most lawn and garden equipment undergo peak use during the summer, chain saw and tiller use peaks during the winter and spring, respectively. A future improvement would be to represent the temporal profiles agricultural equipment according to farming activities and possibly crop calendar. In order to be consistent with the seasonal attributes of reformulated fuels, summertime is defined as May through October while wintertime is considered November through April.

There are three types of weekly use patterns: average, weekday, and weekend. The average, or no peak, use pattern is exhibited by airport ground service and transport refrigeration units. Construction, industrial, and farm equipment display mostly weekday, with some Saturday and less Sunday activity while recreational vehicles and residential lawn and garden equipment exhibit significant weekend use.

The daily activity is distributed by hour with the bulk of the activity occurring between 9 a.m. and 6 p.m., which is the daytime use pattern. Airport ground service equipment is utilized whenever the airport is open, and includes servicing of cargo and regular maintenance. Therefore, the use pattern is primarily during business hours with some off-peak activity. In contrast, transport refrigeration units are operated more evenly throughout the entire day because perishables are shipped at night for morning delivery.

Emissions Module

This module uses emission factors by model year for HC, CO, NO_X, PM, and CO_2. HC emissions are modeled for three types of processes: exhaust, evaporative, and start. The emission factors are expressed in gram per brake horsepower hour (g/bhp-hr), and deterioration rates representing the rate of emission increase per hour (g/bhp-hr^2). The emission factors are calculated by the following equation:

$$EF = ZH + dr * CHrs$$

Where: EF = emission factor, in grams per horsepower-hour (g/bhp-hr)
ZH = zero-hour emission rate or when the equipment is new (g/bhp-hr)
dr = deterioration rate or the increase in ZH emissions as the equipment is used (g/bhp-hr^2)
CHrs = cumulative hours or total number of hours accumulated on the equipment

Since several equipment types use the same engine type, the exhaust emission factors are engine-specific and vary by fuel type, horsepower group and model year. Equipment-specific emission rates are obtained by adjusting the appropriate engine emission rate by the duty cycle of the equipment. The model-year-specific emission rates reflect the effect of reformulated fuels and stringent emission standards for regulations adopted by the ARB. Due to the lack of emission data, the deterioration rates are generally based on on-road emissions data[1], except for gasoline engines less than 25 hp which were obtained from emission test results provided by engine manufacturers. Emission factors for TOG, ROG, and CH_4 are based on the HC emission factor while NO_X is adjusted to calculate a N_2O emission factor. The emission factor for SO_2 is based on fuel sulfur content and brake-specific fuel consumption by equipment.

Evaporative emission factors account for refueling, diurnal, hot soak, running, and resting losses. Evaporative emissions are equipment-specific and dependent on fuel systems. All gasoline off-road equipment is currently uncontrolled for evaporative emissions. However, as ARB implements evaporative controls for off-road equipment, revised evaporative emission rates for controlled equipment will be developed and supported by the OFFROAD model. Evaporative emissions are only necessary for gasoline equipment since diesel fuel has low volatility and LPG systems are pressure sealed. This module also contains correction factors for temperature, ethanol, reformulated fuels, and volatility.

Toxic emissions are estimated as a fraction of the TOG and PM emission inventories using ARB speciation profile data. The profiles were obtained from http://www.arb.ca.gov/ei/speciate/speciate.htm. Acetaldehyde, acrolein, benzene, 1,3-butadiene, formaldehyde, and styrene are based on TOG emissions. PM emissions are used to generate arsenic, cadmium, chromium, lead, manganese, mercury, and nickel.

[1] **California Air Resources Board, "Technical Support Document, Derivation of the EMFAC7E Emission and Correction Factors for On-Road Motor Vehicles," July 1990.**

FIGURE 1: Flowchart of Overall Program Structure of OFFROAD

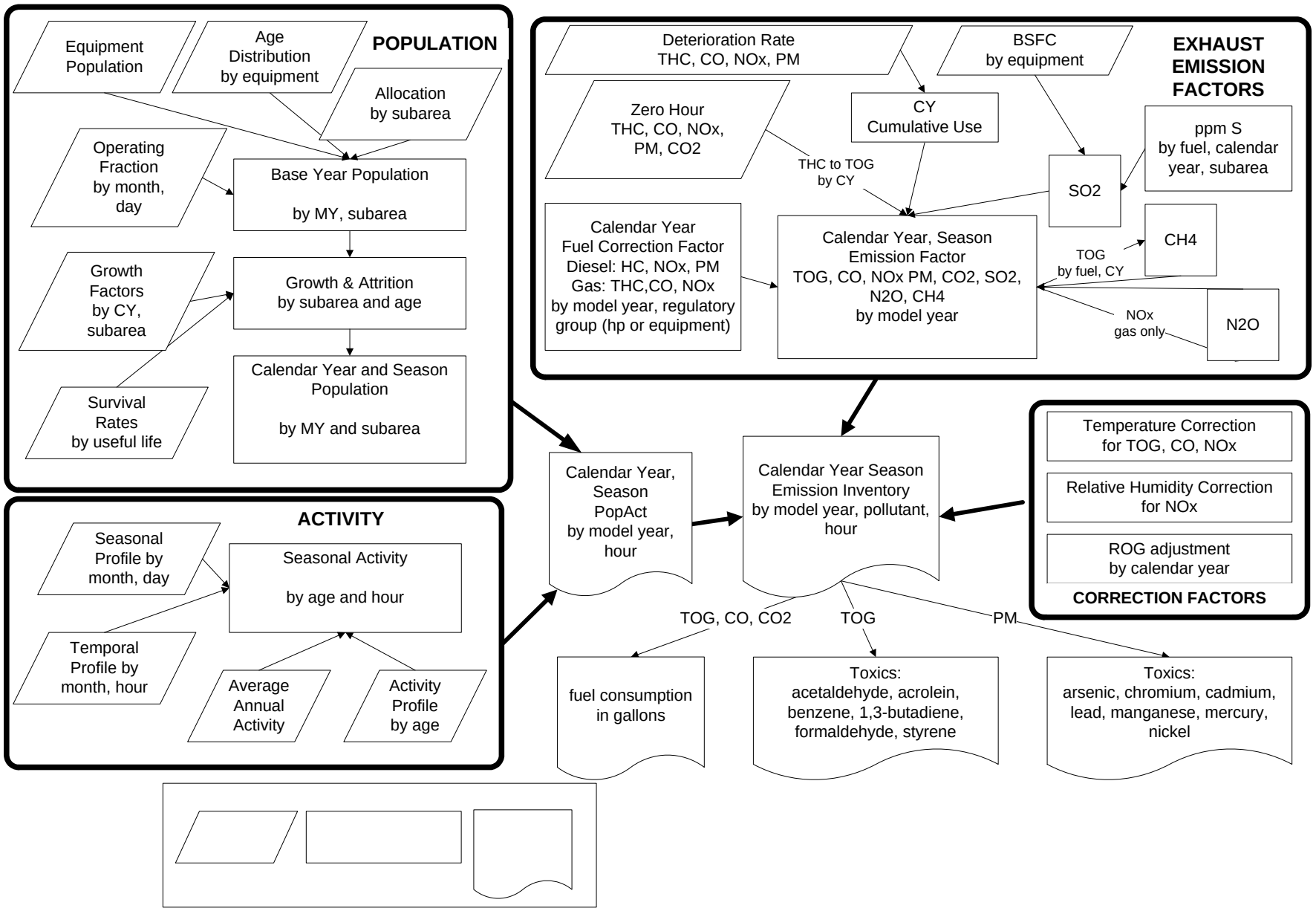

TABLE 1: List of Equipment by Category and Industry

Industry	Equipment
Recreational Vehicles	All Terrain Vehicles (ATVs)
	Golf Carts
	Minibikes
	Off-Road Motorcycles
	Snowmobiles
	Specialty Vehicles Carts
Construction and Mining	Asphalt Pavers
	Bore/Drill Rigs
	Cement and Mortar Mixers
	Concrete/Industrial Saws
	Cranes
	Crawler Tractors
	Crushing/Proc. Equipment
	Dumpers/Tenders
	Excavators
	Graders
	Off-Highway Tractors
	Off-Highway Trucks
	Other Construction Equipment
	Pavers
	Paving Equipment
	Plate Compactors
	Rollers
	Rough Terrain Forklifts
	Rubber Tired Dozers
	Rubber Tired Loaders
	Scrapers
	Signal Boards
	Skid Steer Loaders
	Surfacing Equipment
	Tampers/Rammers
	Tractors/Loaders/Backhoes
	Trenchers
Industrial	Aerial Lifts
	Forklifts
	Other General Industrial Equipmen
	Other Material Handling Equipment
	Sweepers/Scrubbers
Lawn and Garden	Chainsaws
	Chainsaws Preempt
	Chippers/Stump Grinders
	Commercial Turf Equipment
	Front Mowers
	Lawn & Garden Tractors
	Lawn Mowers
	Leaf Blowers/Vacuums
	Other Lawn & Garden Equipment
	Rear Engine Riding Mowers
	Shredders
	Snowblowers
	Tillers
	Trimmers/Edgers/Brush Cutters
	Wood Splitters
Agricultural	2-Wheel Tractors
	Agricultural Mowers
	Agricultural Tractors
	Balers

	Combines
	Hydro Power Units
	Other Agricultural Equipment
	Sprayers
	Swathers
	Tillers
Commercial	Air Compressors
	Gas Compressors
	Generator Sets
	Pressure Washers
	Pumps
	Welders
Logging	Chainsaws
	Fellers/Bunchers
	Shredders
	Skidders
Airport Ground Support	A/C Tug Narrow Body
	A/C Tug Wide Body
	Air Conditioner
	Air Start Unit
	Baggage Tug
	Belt Loader
	Bobtail
	Cargo Loader
	Cargo Tractor
	Cart
	Catering Truck
	Compressor (GSE)
	Deicer
	Forklift
	Fuel Truck
	Generator
	Ground Power Unit
	Hydrant truck
	Lav Cart
	Lav Truck
	Lift
	Maint. Truck
	Other
	Other GSE
	Passenger Stand
	Service Truck
	Sweeper
	Water Truck
Transportation Refrigeration Units	Transport Refrigeration Units
Oil Drilling	Compressors (Workover)
	Drill Rig
	Generator (Drilling)
	Generator (Workover)
	Lift (Drilling)
	Other Drilling Equipment
	Other Workover Equipment
	Pressure Washers
	Pump (Drilling)
	Pump (Workover)
	Snubbing
	Swivel
Military Tactical Support	A/C unit
	Aircraft Support
	Cart
	Communications
	Compressor (Military)
	Crane
	Deicer

	Generator (Military)
	Hydraulic unit
	Lift (Military)
	Light
	Other tactical support equipment
	Pressure Washers
	Pump (Military)
	Start Cart
	Test Stand
	Welder
Dredging	Compressor (Dredging)
	Crane (Dredging)
	Deck/door engine
	Dredger
	Generator (Dredging)
	Hoist/swing/winch
	Other (Dredging)
	Pump (Dredging)
Other Portable	Misc Portable Equipment
Entertainment	Compressor (Entertainment)
	Generator (Entertainment)
Rail Operations	Compressor (Railyard)
	Crane (Rail-CHE)
	Forklift (Rail -CHE)
	Generator (Railyard)
	Materials Handling (Rail-CHE)
	Other Rail Ops (Rail -CHE)
	Sweeper/Scrubber (Rail -CHE)
	Tractor/Loader/Backhoe (Rail -CHE)
	Yard Tractor (Rail -CHE)
Port Operations	Crane (Port -CHE)
	Excavator (Port -CHE)
	Forklift (Port -CHE)
	Material Handling Equip (Port -CHE)
	Other Port Ops (Port -CHE)
	Sweeper/Scrubber (Port -CHE)
	Tractor/Loader/Backhoe (Port -CHE)
	Yard Tractor (Port -CHE)
Pleasure Craft	Personal Water Craft
	Sailboat Auxiliary Inboard Engines
	Sailboat Auxiliary Outboard Engines
	Vessels w/Inboard Engines
	Vessels w/Inboard Jet Engines
	Vessels w/Outboard Engines
	Vessels w/Sterndrive Engines