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Median Life, Annual Activity, and Load Factor Values for Nonroad Engine Emissions Modeling

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Assessment and Standards Division
Office of Transportation and Air Quality
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Purpose

EPA's NONROAD model computes emission inventories for nonroad engines. This report documents the default input values of median life, annual activity, and load factor for various types of nonroad engines. The model uses annual activity and load factor values to calculate yearly emissions for each engine type. In addition, the model uses activity and load factor, in combination with median life, to calculate the fleet age distributions for each engine type, as it projects future (or past) engine populations.

Introduction

This report documents the default annual activity, load factor, and median life values. The model uses the following equation to calculate exhaust emissions from nonroad engines. The derivation of default values for equipment population, average rated power, and emission factors are discussed in reports NR-006b, NR-009b, and NR-010c.

$$Emissions = (Pop)\ (Power)\ (LF)\ (A)\ (EF)$$

where *Pop* = *Engine Population*
Power = *Average Power (hp)*
LF = *Load Factor (fraction of available power)*
A = *Activity (hrs/yr)*
EF = *Emission Factor (g/hp-hr)*

This report also documents the default values for the median life of engines. In the population input files (*.pop) this parameter is expressed in "hours of life at full load." In developing the age distribution for a given equipment type, the model begins by converting the hours-at-full-load to years at average load, on the basis of average activity and load factor, as defined above and as shown in the equation below.

$$Median\ Lifetime\ (years) = \frac{Median\ Life\ (hrs)}{Activity\ (hrs/yr) * \ Load\ Factor}$$

The use of median life in calculating the scrappage and resulting age distribution of each equipment type is explained in report NR-007a, "Calculation of Age Distributions in the Nonroad Model: Growth and Scrappage."

Values Used in NONROAD for Median Life, Annual Activity, and Load Factor

This report describes the default estimates for median life, activity, and load factor used as default data in the input files provided with NONROAD.

Median Life

Engine life varies with engine type and power level. In general, larger engines (i.e., higer rated power and bigger displacement) last longer than smaller ones, and diesel engines last longer than gasoline engines.

The NONROAD model uses median (expected) life estimates based primarily on those used in the OFFROAD model, developed by the California Air Resources Board (ARB)(3). These estimates are listed by horsepower class and engine type in Table 1, with horsepower classes defined in Table 2. In certain cases the ARB horsepower ranges were adjusted to match the ranges used in the NONROAD model. The 120 hp dividing point used by ARB was the 100 hp point in NONROAD; the 250 hp point was used as the 300 hp point in NONROAD; and ARB's 500 hp point was used as the 600 hp dividing point in NONROAD. Additional modifications that EPA made to the ARB median life values for diesel engines, small gasoline engines, and recreational equipment are described below.

Table 1. Expected Engine Life in Hours at Full Load (3, 4)

Engine Type	HP 1	HP 2	HP 3	HP 4	HP 5	HP 6	HP 7	HP 8	HP 9	HP 10
Diesel	2500	2500	2500	4667	4667	4667	7000	7000	7000	--
2-stroke Gasoline	150	200	750	--	--	--	--	--	--	--

4-stroke Gasoline	200	400	750	1500	3000	3000	3000	3000	3000	3000
CNG/ LPG	200	400	750	1500	3000	3000	3000	3000	3000	3000

Table 2. Horsepower Classes for Median Life (3, 4)

HP Class	Diesel	2-stroke	4-stroke
HP 1	≤ 16	≤ 3	≤ 6
HP 2	17-25	3-16	6-16
HP 3	26-50	16-25	16-25
HP 4	51-100	26-50	26-50
HP 5	101-175	51-100	51-100
HP 6	176-300	101-175	101-175
HP 7	301-600	176-250	176-300
HP 8	601-750	301-600	301-600
HP 9	751+	601-750	601-750
HP 10	--	751+	751+

In prior draft versions of NONROAD the median life estimates of most equipment (CI and SI) were based on the values in the 1997 documentation for the ARB OFFROAD model, prepared by Energy and Environmental Analysis (EEA)(3). These are presented in EPA's technical report NR-005a (revised 6/15/1998) and in Table 3 below. For CI these numbers were either 1,250, 2,500, 4,000, or 6,000 hours at full load, depending on rated horsepower.

Table 3. CI Median Life Comparison

Hp Range	Previous NONROAD Median Life	New NONROAD Median Life	Regulatory Useful Life*
0 - 16	1,250	2,500	3,000
16 - 25	2,500	2,500	3,000
25 - 50	2,500	2,500	5,000
50 - 300	4,000	4,667	8,000
300+	6,000	7,000	8,000

* The Regulatory Useful Life is considered to represent in-use loads, rather than full load. NONROAD model diesel load factors range from 0.21 to 0.59.

In researching the issues related to estimation of equipment sales, population, diesel fuel consumption, load factors, and median life, EPA asked EEA for more complete documentation of the values that had been provided to ARB. At EPA's request, EEA supplemented the documentation of their previous work. The resulting report is attached as Appendix B (4).

After reviewing the new EEA report, EPA determined that modifications to the median life estimates were appropriate. Information that EEA gathered from highway diesel engine manufacturers suggested an expected life for heavy-duty diesel highway engines of 7,000 hours at full load. In preparing initial estimates for use in OFFROAD, EEA had reduced this estimate by 15% to compensate for the "rough-duty" use of off-road engines relative to highway engines. This yielded the 6,000 hour estimate mentioned above for engines over 300 hp. In reviewing this work, EPA determined that it did not make sense to reduce the 7000 hour estimate for off-road applications, since when engines are used in off-road applications they are typically derated to compensate for the rougher operating conditions. Thus the horsepower rating of the offroad engine may be lower than its highway counterpart, but its expected life would not be lower.

EEA estimated medium duty diesel engine life to be two-thirds that of the heavy-duty engines and applied that to diesel engines in the range of 50 - 300 hp.

EPA applied this same factor to the 7000 hour value yielding a median life estimate of 4667 hours at full load for 50 - 300 hp engines. For engines in the 16 - 50 hp range EEA based its estimate of 2500 hours at full load on information from light-duty highway diesels. No adjustments were made by EEA or EPA for off-road use, since these engines are typically not used in rough duty applications. For engines under 16 hp EEA had somewhat arbitrarily cut the life estimate of the 16 - 50 hp engines in half, yielding the 1250 hour estimate mentioned above. Since this low estimate was not supported by any data, and since after accounting for load factors it can yield expected life values less than the regulatory useful life set by EPA for these engines, EPA decided to use the 2500 hour estimate in NONROAD for all diesel engines from 0 - 50 hp, rather than have a separate lower life category under 16 hp.

Liquid petroleum gas (LPG) and compressed natural gas (CNG) engines are primarily four-stroke spark-ignition engines and hence have many similarities with four-stroke gasoline engines. Because LPG and CNG engines are similar in design to gasoline engines, their median life is likely to be similar to the median life of gasoline engines. For this reason and the lack of relevant data to the contrary, LPG and CNG engines are assumed to have the same median life as gasoline engines in the NONROAD model.

The values described represent the most comprehensive review available of the engine life associated with engine type and power level. They represent median values of engine life, not distinguishing the engine by make or model. Individual engine models may have longer or shorter median lives. Surveys of engine life by application or engine type are encouraged to improve the estimates shown here.

Small Spark-Ignition Engines (rated at <25 hp)

The median life (the point where 50% of engines have been scrapped) for several applications of nonroad engines have been estimated previously in terms of years of use(5,8). For use in the NONROAD model, these estimates were converted from units of years to units of hours using the equation previously shown. Median life in years from Table 4 was multiplied by hours per year and load factor (described later in the report and given in Table 5) to create the Median Life (Hours at Full Load) entry in Table 4, which is used as input to the NONROAD model.

The final values for the median life used in NONROAD for these selected applications are shown in Table 4. Lower or higher power level engines use the default values from ARB per Tables 1 and 2 above.

Table 4. Median Life for the Bulk of Several Small Spark-Ignition Engine Applications

Application	**Use**	**Power (min.)**	**Power (max.)**	**Median Life (Hours at Full Load)**	**Median Life (Years) (5, 6)**
Lawn Mowers	Residential	1	6	47.9	5.8
	Commercial	1	6	268	2
Trimmer/Edger/Cutter	Residential	0	3	35.3	4.3
	Commercial	0	3	286.8	2.3
Chainsaws	Residential	0	6	39.2	4.3
	Commercial	0	6	191	0.9

Leaf Blower/Vacuum	Residential	0	6	40.4	4.3
	Commercial	0	6	609.7	2.3
Tillers	Residential	0	11	39.4	5.8
	Commercial	0	11	830.7	4.4
Snowblowers	Residential	0	6	12.3	4.4
	Commercial	0	6	209.4	4.4
Commercial Turf	Commercial	3	25	988.9	2.9
Rear Engine Rider	Residential	3	16	79.3	5.8
	Commercial	6	16	627	2.9
Lawn and Garden Tractor	Residential	3	25	114.8	5.8
	Commercial	6	25	920	2.9

Recreational Marine Stern-Drive/Inboard Engines (SD/I)

For purposes of median life the previous publicly available version of NONROAD treated gasoline-powered stern-drive and inboard engines the same as spark-ignition engines over 50 hp. Per Table 1 this meant they were assigned a median life of 3,000 hours at full load. Upon review, it became apparent that when annualized, this result was implausible; this median life, divided by the product of activity and load factor, gave an annualized estimate of 300 years (3,000 hours/(48 hr/year×0.21) = 300 years). To address this issue, NONROAD assumes a median life of 20 years (197 hrs at full load) for all gasoline SD/I engines.

Recreational Equipment

The median life values used for snowmobiles, all-terrain vehicles (ATVs), and offroad motorcycles are given in Table 5. These estimates were developed for the proposed rulemaking for large spark-ignition and recreational engines (19). Since the final rule was just completed in September 2002, changes that have occurred subsequent to the proposal have not been incorporated in this version of the model. The regulatory support document for the final rule provides a detailed description of the most recent median life estimates (21).

Table 5. Median Life for Snowmobiles, All-Terrain Vehicles, and Offroad Motorcycles

Application	Median Life (Hours at Full Load or Miles)	Median Life (Years)
Snowmobiles	174 hours	9
All-Terrain Vehicles	20,410 miles	13
Offroad Motorcycles	21,600 miles	9

Equipment Activity

Activity represents annual equipment usage expressed in hours of operation (hours/year). Except as noted below, we use equipment activity estimates from a 1998 database developed by Power Systems Research, Inc. (PSR), an independent research firm, as default input values in NONROAD. The PSR data represents the most comprehensive review of application-specific activity available to EPA. PSR conducts several yearly surveys of equipment owners and determines a mean usage rate for engines by application and fuel type(7). The PSR methodology is described and evaluated in a report produced by E.H. Pechan & Associates (8).

It should be noted that the activity estimates in the NONROAD model do not currently take into account the effect of equipment age on activity. EPA has encountered some general information indicating that equipment activity declines as the equipment gets older. For example, older pieces of agricultural or construction equipment might be kept as spares to be used if newer equipment breaks down or if another piece of equipment is needed to complete a task once in awhile. Unfortunately, EPA has been unable to obtain precise quantifiable data to model this relationship for any type of nonroad equipment. EPA will continue to look for such data for the development of the nonroad portion of the MOVES Model.

We are unaware of activity estimates specific to LPG and CNG engines. These engines are similar to gasoline engines in that they employ spark-ignition. Because LPG and CNG engines are presumably used in applications where gasoline engines are used, we assume that their usage rates are similar to those for gasoline engines.

The activities in the draft NONROAD2004 model for each equipment type are provided in Appendix A.

Load Factor

Rated power is the maximum power level that an engine is designed to produce at its rated speed. Engines typically operate at a variety of speeds and loads, and operation at rated power for extended periods is rare. To take into account the effect of operation at idle and partial load conditions, as well as transient operation, a load factor is developed to indicate the average proportion of rated power used. For example, at a 0.3 (or 30 percent) load factor, an engine rated at 100 hp would be producing an average of 30 hp over the course of normal operation. Load factor can vary widely for nonroad engines, depending on their usage patterns. Due to the inclusion of engine idle time in the both the load factor and activity inputs of the model, and the dependence of median life on both of these inputs, it is important that any replacement model input data provided by a user would be consistent with this approach.

PSR also estimates the load factor from surveys of equipment users. PSR calculates the fraction of load from the estimate of hours of usage per year, the fuel consumption per year, and the fuel consumption rate at rated power for each engine in the field. A median fraction of available power is determined for specific applications. The load factor is determined from actual and maximum fuel consumption rates for various pieces of equipment. For reference, the PSR methodology is explained in detail in the Pechan report(8).

For the draft NONROAD2004 model, PSR load factors were used with the exceptions described below. As was the case for activity levels, LPG and CNG engines are assigned the load factors for gasoline engines. The load factors in the draft NONROAD2004 model for each equipment type are also provided in Appendix A.

<u>Small (<25 hp) Spark-Ignition Engines</u>

The activity for small spark-ignition engines, mainly lawn and garden equipment, were derived from data supplied to EPA during the comment period for the regulation of these applications. The supporting documentation for those regulations include estimates of activity for a few important applications(5). These alternate values are shown in Table 6 and represent a departure from the PSR values. For applications not shown in Table 6, PSR values were used because the PSR survey includes such categories as construction, agricultural, commercial, and many other engines applications that were not included in the data submitted for the rulemaking.

The load factors for lawn mowers, tillers, snowblowers, rear engine riders, and lawn and garden tractors in Table 6 were also derived from the same data supplied to EPA during the comment period for the regulation of small SI engines.

Table 6. Usage and Load Factors for Several Small Spark-Ignition Engine Applications

Application	**Use**	**Annual Hours**	**Load Factor** (fraction of power)
Lawn Mowers	Residential	25	0.33
	Commercial	406	0.33
Trimmer/Edger/Cutter	Residential	9	0.91
	Commercial	137	0.91
Chainsaws	Residential	13	0.70
	Commercial	303	0.70
Leaf Blower\Vacuum	Residential	10	0.94
	Commercial	282	0.94
Tillers	Residential	17	0.40
	Commercial	472	0.40
Snowblowers	Residential	8	0.35
	Commercial	136	0.35
Commercial Turf	Commercial	682	0.60
Rear Engine Rider	Residential	36	0.38
	Commercial	569	0.38
Lawn and Garden Tractor	Residential	45	0.44
	Commercial	721	0.44

For the three most populous handheld applications (i.e., chainsaws, trimmers/edgers/brush cutters, and blowers/vacuums), the previous version of NONROAD assumed a load factor of 0.50. The estimate of 0.50 was supplied by manufacturers to the California Air Resource Board in 1990 and is based on manufacturers' belief that it accurately reflects the typical usage pattern of most portable two-stroke power equipment. In support of a more recent effort to analyze the test cycle currently used for certification of Phase 1 handheld engines, manufacturers monitored the in-use operation of a number of chainsaws, trimmers/edgers/brush cutters, and blowers/vacuums to determine the appropriate weighting of wide open throttle (WOT) and idle operation for certification testing purposes. Based on this information, the load factors for chainsaws, trimmers/edgers/brush cutters, and blowers/vacuums are now 0.70, 0.91, and 0.94, respectively (6).

For commercial turf equipment, the previous load factor of 0.50 was revised to 0.60, based on 1998 PSR data.

Many of the small spark-ignited engines are used in lawn and garden equipment applications, and lawn and garden equipment is used both by commercial and residential users. The commercial users are grounds keepers for nonresidential, large apartment complexes, and some single-family homes. Commercial equipment therefore has significantly different usage in terms of hours per year and weekday and weekend day than residential equipment. To account for these differences in equipment usage, separate SCC's are used to distinguish commercial from residential lawn and garden equipment.

Recreational Marine Engines

As described in the technical report on nonroad engine populations (2) , recreational marine engines are divided into three applications; inboard, outboard, and personal watercraft. Due to the similarity of engines, the inboard category includes the inboard/outboard sterndrive engines formerly considered as a separate SCC category. The inboard engines are associated with the PSR category "powerboats."

The June 1998 draft of the NONROAD model used fuel consumption data to estimate activity for outboard engines (9). The April 1999 draft version and subsequent drafts of the model have used activity data collected during the recreational marine rulemaking process, provided by the National Marine Manufacturers Association and individual marine vessel manufacturers (10). Draft NONROAD2004 continues to use these estimates, which are shown in Table 7.

Table 7. Recreational Marine Activity and Load Factors

Recreational Marine Engine/Equipment Type	**Activity (hours/year)**	**Load Factor (fraction of power)**
Four-stroke Inboards	47.6	0.21
Two-stroke Outboards	34.8	0.21
Personal Watercraft	77.3	0.21

Based on other comments, we revised the load factor to reflect the average load for the marine engine certification test cycle (20.7%) . In-use data for load factor arenot available., and the PSR estimates of load factor (32% for outboard, 38% for inboard, and 42% for personal watercraft) are not currently documented.

Recreational Equipment

In the course of the rulemaking process for recreational equipment and large spark-ignition engines, the activity and load factor estimates for recreational equipment (i.e., snowmobiles, all-terrain vehicles, and off-road motorcycles) were updated in draft NONROAD2002 (11,12). In estimating operating hoursfor recreational vehicles, a number of sources are available for each vehicle type.

For snowmobiles activity information is available from (a) studies on the economic impact of snowmobile operation in seven states (12-18), (b) consumer-satisfaction survey results from the snowmobile industry, and (c) snowmobile enthusiasts' self-reported usage estimates compiled and provided by the Bluewater Network (an environmental organization). These sources presented usage information in terms of average or typical miles ridden per year. To convert the mileage estimates to operating hours, we estimated the average speed for typical snowmobile operation.

The information available on average speed was collected on instrumented machines during development of an emissions test cycle for snowmobiles, performed by Southwest Research Institute under sponsorship of the International Snowmobile Manufacturers Association (11). The cycle development work encompassed operation over varied conditions, including moderate and aggressive trail riding, lake riding, off-trail freestyle riding, and operation with single and double riders. Sled speeds ranged from 14 to 32 mph, although the bulk of the data falls between 20 and 30 mph. Because of the large variation in speed estimates, it is difficult to determine what average speed is the most representative. We know that the correct speed is somewhere within this range and that the mode of the estimates fell at the midpoint of the range. Therefore, we are using an average speed of 23 mph for snowmobile operation. We believe that this value is reasonable and it is supported by the snowmobile manufacturers per a recent discussion .

Having estimated average speed, it is possible to convert the estimated average yearly mileage into yearly operating hours. The range of average yearly mileage estimates available to us is 540 to 1,800 miles. Manufacturers have indicated that for winters with average or above average snowfall, the average yearly mileage is approximately 1,500 miles and that for poorer winters, with less than average snowfall, the average yearly mileage is approximately 1,200 miles. These estimates fall well within the range of estimates given above . In fact, several of the state economic studies indicated that their estimates for mileage were low due to poor snowfall during the winter in which they performed their studies. Therefore, we estimate the average yearly travel distance for snowmobiles at 1,300 miles. Given an average speed of 23 mph and an average mileage of 1,300 miles, we estimate the average yearly activity at 57 hours per year.

For snowmobiles, the load factor of 0.34 is derived from data collected during the cycle development project described above (11).

Based on data that has become available since the publication of the Proposed Rule for control of emissions from recreational engines, we have revised the activity estimate for all-terrain vehicles (ATVs). For reference, the prior estimate, which is superseded by the estimate described in this report and referenced Rule documents, is presented and described in the docket memorandum *Emission Modeling for Recreational Vehicles* (EPA420-F-00-051, Docket A-98-01).[1]

Data sources used to derive the revised estimate include: (a) A phone survey sponsored by Honda in which owners of TRX model utility ATVs were requested to report odometer and hour-meter readings, (b) a database of warranty claim information provided by another manufacturer, which included odometer and hour-meter readings, (c) a national survey of ATV population and usage sponsored by the Consumer Product Safety Commission (20), and (d) a "market panel" survey of ATV usage sponsored by major manufacturers. The manufacturers' survey was performed during the same time period as the CPSC study, employed similar interview methods and obtained very similar results.

Based on these sources, ATV activity has been re-estimated at 1,570 miles/year. This value is intended to represent a national annual average. and may be further revised following additional analyses in support of the rulemaking. For a more detailed description of the derivation of this estimate and any minor updates to it, see the *Final Regulatory Support Document: Control of Emissions from Unregulated Nonroad Engines* (21).

For off-road motorcycles, there are two sources of information on activity or usage rates. The first source is information provided by the Motorcycle Industry Council (MIC). MIC periodically conducts surveys on motorcycle usage. . MIC uses two methods to estimate off-road motorcycle usage from the survey results. Method one is based on the results of a single question that asks the respondent how many miles they rode in the last year. Method two is based on the multiplication of the responses from three questions: (a) during how many months of the year did the respondent ride?, (b) how many days during a typical month did the respondent ride?, and (c) how many hours did the respondent ride in a typical day? The estimate from method one is 222 miles per year and that from method two is 1,260 miles per year. MIC has suggested that method one is the more appropriate estimate because method two may compound any error that exists in the results of each of the three questions. We have concerns with the results of the MIC survey because the values for method one and two are dramatically different. Activity expressed in miles/year is consistent with corresponding emission factors for off-road motorcycles, which are expressed in grams/mile.

The second source of information is a study done in 1994 by the Oak Ridge National Laboratory (ORNL) titled, "Fuel Used for Off-Road Recreation" (22). This study estimated total average fuel usage for off-road motorcycles at 59 gallons/year, which ORNL considers to be a

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[1] This memorandum supplements the *Advance Notice of Proposed Rulemaking: Control of Emissions from Nonroad Large Spark Ignition Engines, Recreational Engines (Marine and Land-based), and Highway Motorcycles* (November 20, 2000). See http://www.otaq.gov/otaq/recveh.htm.

“medium” estimate. Recent data from California (), combined with older data collected at Southwest Research Institute (SwRI) , suggest that the average fuel economy for off-road motorcycles is approximately 50 miles per gallon (mpg), as tested over the Federal Test Procedure (FTP) . This estimate may be too high for actual operation off-road, so we assume an estimate of 40 mpg. By multiplying the annual average fuel usage by the average fuel economy, we arrive at an estimate of approximately 2,400 miles per year.

Due to uncertainty related to interview methods in the MIC survey, we have estimated motorcycle activity based on fuel use as estimated by ORNL, and fuel economy estimated in-use and on the FTP, as described above. Thus, we estimate annual activity at 2,400 miles per year for two and four-stroke off-road motorcycles. As of this writing, this estimate is under review and may be revised to incorporate analyses supporting the final rule covering recreational vehicles.

For ATVs and off-road motorcycles, load factors are no longer necessary, since the emission factors are expressed as grams per mile. As a result, for these equipment types, load factors and average rated horsepowers are simply set to 1.0 in the input file. This modification effectively converts the emissions calculation from a power-output basis to a distance-traveled basis, similar to that used for cars and trucks. The operating hours, mileage, and load factors used for recreational vehicles are listed in Table 8.

Table 8. Activity and Load Factors for Recreational Vehicles

Application	Type	Load Factor	Hours per Year	Mileage per Year
ATVs	2 & 4-stroke	1.0*	----	1,608
Off-Road Motorcycles	2 & 4-stroke	1.0*	----	1,600
Snowmobiles	2-stroke	0.34	57	----

* Average rated horsepower is also set at 1.0, effectively removing power output (rated power * load factor) from the equation; emissions are thus calculated on the basis of EF*Act*Population, where units equal g/mile*miles/year = g/year, which the model converts to tons/year.

Compression-Ignition (CI) Equipment

For CI equipment, we are using activity estimates from the 1998 PSR database.

The PSR CI load factors used in previous versions of NONROAD, which are based on information obtained from surveys of equipment owners, have been replaced by load factors obtained from actual engine testing over several transient cycles. The transient cycle development and engine tests were conducted by Southwest Research Institute under contract to EPA (with some of the cycle development work also co-sponsored by the Engine Manufacturers

Association) (23, 24, 25). Seven transient cycles were developed: agricultural tractor, backhoe loader, crawler dozer, rubber-tire loader, skid-steer loader, arc welder, and excavator. For the rubber-tire loader, skid-steer loader, and arc welder cycles, both “typical transient” and “high transient” versions of the cycles were developed; for this work, the typical versions were used.

The load factors for the seven transient cycles are given in Table 9. The seven load factors were further binned into three categories, “High,” “Low,” and “steady-state ” (represented by an average of the seven cycles). . We consider this approach simpler and more defensible, given the limited number of cycles designed to represent in-use operation for specific equipment types and uncertainty in extrapolating the test data to broader equipment populations. This approach is also consistent with that used to develop the new transient adjustment factors in the model . The high load factor bin includes the following cycles: agricultural tractor (LF=0.78), crawler dozer (LF=0.58), rubber-tire loader (LF=0.48), and excavator (LF=0.53). The low load factor bin includes the remaining cycles: backhoe/loader (LF=0.21), skid-steer loader (LF=0.23), and arc welder (LF=0.19). The “high” load factor cycles were averaged to obtain a composite High LF (0.59). Similarly, the “low” load factor cycles were averaged to obtain a composite Low LF (0.21). The load factors for all seven cycles were averaged to obtain a composite 7-cycle average “steady-state” LF (0.43). See Table 9.

Table 9. Compression-Ignition Load Factors			
Cycle	Cycle Load Factors	Assignment	Average
Agricultural Tractor	0.78	High	0.59
Crawler Dozer	0.58		
Rubber-tired Loader	0.48		
Excavator	0.53		
Backhoe Loader	0.21	Low	0.21
Skid-steer Loader	0.23		
Arc Welder	0.19		
7-cycle average	---	Steady-state	0.43

Each diesel nonroad equipment type was assigned one of these three composite load factors (Hi LF, Lo LF, or 7-cycle average). To apply these load factors, we matched nonroad applications with the test cycle that most closely represents the nonroad activity for the application. Table 10 lists the diesel nonroad applications used in the NONROAD model and the load factor assignment considered representative of that application. If steady-state operation is typical of an application, the 7-cycle average load factor was assigned.

The resulting load factors for each equipment type are provided in Appendix A.

Table 10. CI Load Factor Assignments by Equipment Type

SCC	Equipment Type	Representative Cycle	Load Factor Assignment
2270001000	Recreational Vehicles All	Backhoe	Lo LF
2270001020	Recreational Vehicles Snowmobiles	None	Avg 7-cycle
2270001030	Recreational Vehicles All Terrain Vehicles	None	Avg 7-cycle
2270001040	Recreational Vehicles Minibikes	None	Avg 7-cycle
2270001050	Recreational Vehicles Golf Carts	None	Avg 7-cycle
2270001060	Recreational Vehicles Speciality Vehicle Carts	Backhoe	Lo LF
2270002003	Construction Equipment Pavers	Crawler	Hi LF
2270002006	Construction Equipment Tampers/Rammers	None	Avg 7-cycle
2270002009	Construction Equipment Plate Compactors	None	Avg 7-cycle
2270002015	Construction Equipment Rollers	Crawler	Hi LF
2270002018	Construction Equipment Scrapers	Crawler	Hi LF
2270002021	Construction Equipment Paving Equipment	Crawler	Hi LF
2270002024	Construction Equipment Surfacing Equipment	Crawler	Hi LF
2270002027	Construction Equipment Signal Boards	None	Avg 7-cycle
2270002030	Construction Equipment Trenchers	Crawler	Hi LF
2270002033	Construction Equipment Bore/Drill Rigs	None	Avg 7-cycle
2270002036	Construction Equipment Excavators	Excavator	Hi LF
2270002039	Construction Equipment Concrete/Industrial Saws	Crawler	Hi LF
2270002042	Construction Equipment Cement & Mortar Mixers	None	Avg 7-cycle
2270002045	Construction Equipment Cranes	None	Avg 7-cycle
2270002048	Construction Equipment Graders	Crawler	Hi LF
2270002051	Construction Equipment Off-highway Trucks	Crawler	Hi LF
2270002054	Construction Equipment Crushing/Proc. Equipment	None	Avg 7-cycle
2270002057	Construction Equipment Rough Terrain Forklifts	RTLoader	Hi LF
2270002060	Construction Equipment Rubber Tire Loaders	RTLoader	Hi LF
2270002063	Construction Equipment Rubber Tire Dozers	Crawler	Hi LF
2270002066	Construction Equipment Tractors/Loaders/Backhoes	Backhoe	Lo LF
2270002069	Construction Equipment Crawler Dozer	Crawler	Hi LF
2270002072	Construction Equipment Skid Steer Loaders	SSLoader	Lo LF
2270002075	Construction Equipment Off-Highway Tractors	Crawler	Hi LF
2270002078	Construction Equipment Dumpers/Tenders	Backhoe	Lo LF
2270002081	Construction Equipment Other Construction Equipment	Crawler	Hi LF
2270003010	Industrial Equipment Aerial Lifts	Backhoe	Lo LF
2270003020	Industrial Equipment Forklifts	RTLoader	Hi LF
2270003030	Industrial Equipment Sweepers/Scrubbers	None	Avg 7-cycle
2270003040	Industrial Equipment Other General Industrial Equipment	None	Avg 7-cycle
2270003050	Industrial Equipment Other Material Handling Equipment	Backhoe	Lo LF
2270003060	Industrial Equipment AC\Refrigeration	None	Avg 7-cycle
2270003070	Terminal Tractors	Crawler	Hi LF
2270004000	Lawn & Garden Equipment ALL	None	Avg 7-cycle
2270004010	Lawn & Garden Equipment Lawn mowers (Residential)	None	Avg 7-cycle
2270004011	Lawn & Garden Equipment Lawn mowers (Commercial)	None	Avg 7-cycle
2270004015	Lawn & Garden Equipment Rotary Tillers < 6 HP	None	Avg 7-cycle
2270004016	Lawn & Garden Equipment Rotary Tillers < 6 HP	None	Avg 7-cycle
2270004020	Lawn & Garden Equipment Chain Saws < 6 HP	None	Avg 7-cycle
2270004021	Lawn & Garden Equipment Chain Saws < 6 HP	None	Avg 7-cycle

Table 10. CI Load Factor Assignments by Equipment Type

SCC	Equipment Type	Representative Cycle	Load Factor Assignment
2270004025	Lawn & Garden Equipment Trimmers/Edgers/Brush	None	Avg 7-cycle
2270004026	Lawn & Garden Equipment Trimmers/Edgers/Brush	None	Avg 7-cycle
2270004030	Lawn & Garden Equipment Leafblowers/Vacuums	None	Avg 7-cycle
2270004031	Lawn & Garden Equipment Leafblowers/Vacuums	None	Avg 7-cycle
2270004035	Lawn & Garden Equipment Snowblowers	None	Avg 7-cycle
2270004036	Lawn & Garden Equipment Snowblowers (Commercial)	None	Avg 7-cycle
2270004040	Lawn & Garden Equipment Rear Engine Riding Mowers	None	Avg 7-cycle
2270004041	Lawn & Garden Equipment Rear Engine Riding Mowers	None	Avg 7-cycle
2270004045	Lawn & Garden Equipment Front Mowers	None	Avg 7-cycle
2270004046	Lawn & Garden Equipment Front Mowers (Commercial)	None	Avg 7-cycle
2270004050	Lawn & Garden Equipment Shredders < 6 HP	None	Avg 7-cycle
2270004051	Lawn & Garden Equipment Shredders < 6 HP	None	Avg 7-cycle
2270004055	Lawn & Garden Equipment Lawn & Garden Tractors	None	Avg 7-cycle
2270004056	Lawn & Garden Equipment Lawn & Garden Tractors	None	Avg 7-cycle
2270004060	Lawn & Garden Equipment Wood Splitters	None	Avg 7-cycle
2270004061	Lawn & Garden Equipment Wood Splitters (Commercial)	None	Avg 7-cycle
2270004065	Lawn & Garden Equipment Chippers/Stump Grinders	None	Avg 7-cycle
2270004066	Lawn & Garden Equipment Chippers/Stump Grinders	None	Avg 7-cycle
2270004071	Lawn & Garden Equipment Commercial Turf Equipment	None	Avg 7-cycle
2270004075	Lawn & Garden Equipment Other Lawn & Garden	None	Avg 7-cycle
2270004076	Lawn & Garden Equipment Other Lawn & Garden	None	Avg 7-cycle
2270005010	Farm Equipment 2-Wheel Tractors	AgTractor	Hi LF
2270005015	Farm Equipment Agricultural Tractors	AgTractor	Hi LF
2270005020	Farm Equipment Combines	AgTractor	Hi LF
2270005025	Farm Equipment Balers	AgTractor	Hi LF
2270005030	Farm Equipment Agricultural Mowers	AgTractor	Hi LF
2270005035	Farm Equipment Sprayers	AgTractor	Hi LF
2270005040	Farm Equipment Tillers > 6 HP	AgTractor	Hi LF
2270005045	Farm Equipment Swathers	AgTractor	Hi LF
2270005050	Farm Equipment Hydro Power Units	None	Avg 7-cycle
2270005055	Farm Equipment Other Agricultural Equipment	AgTractor	Hi LF
2270005060	Farm Equipment Irrigation Sets	None	Avg 7-cycle
2270006000	Light Commercial ALL	None	Avg 7-cycle
2270006005	Light Commercial Generator Sets	None	Avg 7-cycle
2270006010	Light Commercial Pumps	None	Avg 7-cycle
2270006015	Light Commercial Air Compressors	None	Avg 7-cycle
2270006020	Light Commercial Gas Compressors	None	Avg 7-cycle
2270006025	Light Commercial Welders	ArcWelder	Lo LF
2270006030	Light Commercial Pressure Washers	None	Avg 7-cycle
2270007005	Logging Equipment Chain Saws > 6 HP	RTLoader	Hi LF
2270007010	Logging Equipment Shredders > 6 HP	RTLoader	Hi LF
2270007015	Logging Equipment Forest Equipment	RTLoader	Hi LF
2270008005	Airport Service Equipment Airport Support Equipment	RTLoader	Hi LF
2270009010	Other Underground Mining Equipment	Backhoe	Lo LF
2270010010	Other Oil Field Equipment	None	Avg 7-cycle
2282020005	Recreational Pleasure Craft, Inboards	None	Avg 7-cycle

Table 10. CI Load Factor Assignments by Equipment Type			
SCC	**Equipment Type**	**Representative Cycle**	**Load Factor Assignment**
2282020010	Recreational Pleasure Craft, Outboards	None	Avg 7-cycle
2282020015	Recreational Pleasure Craft, Personal Water Craft	None	Avg 7-cycle
2282020025	Recreational Pleasure Craft, Sailboat Aux. Outboard	None	Avg 7-cycle
2285002015	Railway Maintenance	Backhoe	Lo LF

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[2] This memorandum supplements the *Advance Notice of Proposed Rulemaking: Control of Emissions from Nonroad Large Spark Ignition Engines, Recreational Engines (Marine and Land-based), and Highway Motorcycles* (November 20, 2000). See http://www.otaq.gov/otaq/recveh.htm.

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Appendix A

Load Factor and Activity Estimates in Draft NONROAD2004

SCC	Equipment Description	Load Factor (fraction of power)	Activity (hours/year)
2260001010	2-Stroke Motorcycles: Off-Road	1.00	1600*
2260001020	2-Stroke Snowmobiles	0.34	57
2260001030	2-Stroke All Terrain Vehicles	1.00	1608*
2260001050	2-Stroke Golf Carts	0.46	1080
2260001060	2-Stroke Specialty Vehicle Carts	0.58	65
2260002003	2-Stroke Asphalt Pavers	0.66	392
2260002006	2-Stroke Tampers/Rammers	0.55	160
2260002009	2-Stroke Plate Compactors	0.55	166
2260002012	2-Stroke Concrete Pavers	0.55	0
2260002015	2-Stroke Rollers	0.62	621
2260002018	2-Stroke Scrapers	0.70	540
2260002021	2-Stroke Paving Equipment	0.59	175
2260002024	2-Stroke Surfacing Equipment	0.49	488
2260002027	2-Stroke Signal Boards	0.72	318
2260002030	2-Stroke Trenchers	0.66	402
2260002033	2-Stroke Bore/Drill Rigs	0.79	107
2260002036	2-Stroke Excavators	0.53	378
2260002039	2-Stroke Concrete/Industrial Saws	0.78	610
2260002042	2-Stroke Cement & Mortar Mixers	0.59	84
2260002045	2-Stroke Cranes	0.47	415
2260002048	2-Stroke Graders	0.64	504
2260002051	2-Stroke Off-highway Trucks	0.80	450
2260002054	2-Stroke Crushing/Proc. Equipment	0.85	241
2260002057	2-Stroke Rough Terrain Forklifts	0.63	413
2260002060	2-Stroke Rubber Tire Loaders	0.71	512
2260002063	2-Stroke Rubber Tire Dozers	0.75	900
2260002066	2-Stroke Tractors/Loaders/Backhoes	0.48	870
2260002069	2-Stroke Crawler Dozer	0.80	700
2260002072	2-Stroke Skid Steer Loaders	0.58	310
2260002075	2-Stroke Off-Highway Tractors	0.70	155
2260002078	2-Stroke Dumpers/Tenders	0.41	127
2260002081	2-Stroke Other Construction Equipment	0.48	371
2260003010	2-Stroke Aerial Lifts	0.46	361
2260003020	2-Stroke Forklifts	0.30	1800
2260003030	2-Stroke Sweepers/Scrubbers	0.71	516
2260003040	2-Stroke Other General Industrial Equipment	0.54	713
2260003050	2-Stroke Other Material Handling Equipment	0.53	386
2260003060	2-Stroke Refrigeration	0.46	605
2260003070	2-Stroke Terminal Tractors	0.78	827
2260004010	2-Stroke Lawn mowers (Residential)	0.33	25
2260004011	2-Stroke Lawn mowers (Commercial)	0.33	406
2260004015	2-Stroke Rotary Tillers < 6 HP (Residential)	0.40	17
2260004016	2-Stroke Rotary Tillers < 6 HP (Commercial)	0.40	472
2260004020	2-Stroke Chain Saws < 6 HP (Residential)	0.70	13
2260004021	2-Stroke Chain Saws < 6 HP (Commercial)	0.70	303
2260004025	2-Stroke Trimmers/Edgers/Brush Cutters	0.91	9
2260004026	2-Stroke Trimmers/Edgers/Brush Cutters	0.91	137
2260004030	2-Stroke Leafblowers/Vacuums (Residential)	0.94	10
2260004031	2-Stroke Leafblowers/Vacuums (Commercial)	0.94	282
2260004035	2-Stroke Snowblowers (Residential)	0.35	8
2260004036	2-Stroke Snowblowers (Commercial)	0.35	136
2260004040	2-Stroke Rear Engine Riding Mowers (Res.)	0.38	36

Load Factor and Activity Estimates in Draft NONROAD2004

SCC	Equipment Description	Load Factor (fraction of power)	Activity (hours/year)
2260004041	2-Stroke Rear Engine Riding Mowers (Comm.)	0.38	569
2260004045	2-Stroke Front Mowers (Residential)	0.65	86
2260004046	2-Stroke Front Mowers (Commercial)	0.65	86
2260004050	2-Stroke Shredders < 6 HP (Residential)	0.80	50
2260004051	2-Stroke Shredders < 6 HP (Commercial)	0.80	50
2260004055	2-Stroke Lawn & Garden Tractors (Residential)	0.44	45
2260004056	2-Stroke Lawn & Garden Tractors (Commercial)	0.44	721
2260004060	2-Stroke Wood Splitters (Residential)	0.69	76
2260004061	2-Stroke Wood Splitters (Commercial)	0.69	76
2260004065	2-Stroke Chippers/Stump Grinders (Res.)	0.78	488
2260004066	2-Stroke Chippers/Stump Grinders (Comm.)	0.78	488
2260004070	2-Stroke Commercial Turf Equipment (Res.)	0.60	682
2260004071	2-Stroke Commercial Turf Equipment (Comm)	0.60	682
2260004075	2-Stroke Other Lawn & Garden Equipment	0.58	61
2260004076	2-Stroke Other Lawn & Garden Equipment	0.58	61
2260005010	2-Stroke 2-Wheel Tractors	0.62	286
2260005015	2-Stroke Agricultural Tractors	0.62	550
2260005020	2-Stroke Combines	0.74	125
2260005025	2-Stroke Balers	0.62	68
2260005030	2-Stroke Agricultural Mowers	0.48	175
2260005035	2-Stroke Sprayers	0.65	80
2260005040	2-Stroke Tillers > 6 HP	0.71	43
2260005045	2-Stroke Swathers	0.52	95
2260005050	2-Stroke Hydro Power Units	0.56	450
2260005055	2-Stroke Other Agricultural Equipment	0.55	124
2260005060	2-Stroke Irrigation Sets	0.60	716
2260006005	2-Stroke Light Commercial Generator Set	0.68	115
2260006010	2-Stroke Light Commercial Pumps	0.69	221
2260006015	2-Stroke Light Commercial Air Compressors	0.56	484
2260006020	2-Stroke Light Commercial Gas Compressors	0.85	6000
2260006025	2-Stroke Light Commercial Welders	0.68	408
2260006030	2-Stroke Light Commercial Pressure Wash	0.85	115
2260007005	2-Stroke Logging Equipment Chain Saws > 6 HP	0.70	303
2260007010	2-Stroke Logging Equipment Shredders > 6 HP	0.80	50
2260007015	2-Stroke Logging Equipment Skidders	0.70	350
2260007020	2-Stroke Logging Equipment Fellers/Bunchers	0.70	0
2260008005	2-Stroke Airport Support Equipment	0.56	681
2260009010	2-Stroke Other Underground Mining Equipment	0.80	260
2260010010	2-Stroke Other Oil Field Equipment	0.90	1104
2265001010	4-Stroke Motorcycles: Off-Road	1.00	1600
2265001020	4-Stroke Snowmobiles	0.34	57
2265001030	4-Stroke All Terrain Vehicles	1.00	1608
2265001050	4-Stroke Golf Carts	0.46	1080
2265001060	4-Stroke Specialty Vehicle Carts	0.58	65
2265002003	4-Stroke Asphalt Pavers	0.66	392
2265002006	4-Stroke Tampers/Rammers	0.55	160
2265002009	4-Stroke Plate Compactors	0.55	166
2265002012	4-Stroke Concrete Pavers	0.55	0
2265002015	4-Stroke Rollers	0.62	621
2265002018	4-Stroke Scrapers	0.70	540
2265002021	4-Stroke Paving Equipment	0.59	175
2265002024	4-Stroke Surfacing Equipment	0.49	488

Load Factor and Activity Estimates in Draft NONROAD2004

SCC	Equipment Description	Load Factor (fraction of power)	Activity (hours/year)
2265002027	4-Stroke Signal Boards	0.72	318
2265002030	4-Stroke Trenchers	0.66	402
2265002033	4-Stroke Bore/Drill Rigs	0.79	107
2265002036	4-Stroke Excavators	0.53	378
2265002039	4-Stroke Concrete/Industrial Saws	0.78	610
2265002042	4-Stroke Cement & Mortar Mixers	0.59	84
2265002045	4-Stroke Cranes	0.47	415
2265002048	4-Stroke Graders	0.64	504
2265002051	4-Stroke Off-highway Trucks	0.80	450
2265002054	4-Stroke Crushing/Proc. Equipment	0.85	241
2265002057	4-Stroke Rough Terrain Forklifts	0.63	413
2265002060	4-Stroke Rubber Tire Loaders	0.71	512
2265002063	4-Stroke Rubber Tire Dozers	0.75	900
2265002066	4-Stroke Tractors/Loaders/Backhoes	0.48	870
2265002069	4-Stroke Crawler Tractors	0.80	700
2265002072	4-Stroke Skid Steer Loaders	0.58	310
2265002075	4-Stroke Off-Highway Tractors	0.70	155
2265002078	4-Stroke Dumpers/Tenders	0.41	127
2265002081	4-Stroke Other Construction Equipment	0.48	371
2265003010	4-Stroke Aerial Lifts	0.46	361
2265003020	4-Stroke Forklifts	0.30	1800
2265003030	4-Stroke Sweepers/Scrubbers	0.71	516
2265003040	4-Stroke Other General Industrial Equipment	0.54	713
2265003050	4-Stroke Other Material Handling Equipment	0.53	386
2265003060	4-Stroke Industial AC\Refrigeration	0.46	605
2265003070	4-Stroke Terminal Tractors	0.78	827
2265004010	4-Stroke Lawn mowers (Residential)	0.33	25
2265004011	4-Stroke Lawn mowers (Commercial)	0.33	406
2265004015	4-Stroke Rotary Tillers < 6 HP (Residential)	0.40	17
2265004016	4-Stroke Rotary Tillers < 6 HP (Commercial)	0.40	472
2265004020	4-Stroke Chain Saws < 6 HP (Residential)	0.70	13
2265004021	4-Stroke Chain Saws < 6 HP (Commercial)	0.70	303
2265004025	4-Stroke Trimmers/Edgers/Brush Cutters	0.91	9
2265004026	4-Stroke Trimmers/Edgers/Brush Cutters	0.91	137
2265004030	4-Stroke Leafblowers/Vacuums (Residential)	0.94	10
2265004031	4-Stroke Leafblowers/Vacuums (Commercial)	0.94	282
2265004035	4-Stroke Snowblowers (Residential)	0.35	8
2265004036	4-Stroke Snowblowers (Commercial)	0.35	136
2265004040	4-Stroke Rear Engine Riding Mowers (Res.)	0.38	36
2265004041	4-Stroke Rear Engine Riding Mowers (Comm)	0.38	569
2265004045	4-Stroke Front Mowers (Residential)	0.65	86
2265004046	4-Stroke Front Mowers (Commercial)	0.65	86
2265004050	4-Stroke Shredders < 6 HP (Residential)	0.80	50
2265004051	4-Stroke Shredders < 6 HP (Commercial)	0.80	50
2265004055	4-Stroke Lawn & Garden Tractors (Residential)	0.44	45
2265004056	4-Stroke Lawn & Garden Tractors (Commercial)	0.44	721
2265004060	4-Stroke Wood Splitters (Residential)	0.69	76
2265004061	4-Stroke Wood Splitters (Commercial)	0.69	76
2265004065	4-Stroke Chippers/Stump Grinders (Res.)	0.78	488
2265004066	4-Stroke Chippers/Stump Grinders (Comm.)	0.78	488
2265004070	4-Stroke Commercial Turf Equipment (Res.)	0.60	682
2265004071	4-Stroke Commercial Turf Equipment (Comm)	0.60	682

Load Factor and Activity Estimates in Draft NONROAD2004

SCC	Equipment Description	Load Factor (fraction of power)	Activity (hours/year)
2265004075	4-Stroke Other Lawn & Garden Equipment	0.58	61
2265004076	4-Stroke Other Lawn & Garden Equipment	0.58	61
2265005010	4-Stroke 2-Wheel Tractors	0.62	286
2265005015	4-Stroke Agricultural Tractors	0.62	550
2265005020	4-Stroke Combines	0.74	125
2265005025	4-Stroke Balers	0.62	68
2265005030	4-Stroke Agricultural Mowers	0.48	175
2265005035	4-Stroke Sprayers	0.65	80
2265005040	4-Stroke Tillers > 5 HP	0.71	43
2265005045	4-Stroke Swathers	0.52	95
2265005050	4-Stroke Hydro Power Units	0.56	450
2265005055	4-Stroke Other Agricultural Equipment	0.55	124
2265005060	4-Stroke Irrigation Sets	0.60	716
2265006005	4-Stroke Light Commercial Generator Sets	0.68	115
2265006010	4-Stroke Light Commercial Pumps	0.69	221
2265006015	4-Stroke Light Commercial Air Compressors	0.56	484
2265006020	4-Stroke Light Commercial Gas Compressors	0.85	6000
2265006025	4-Stroke Light Commercial Welders	0.68	408
2265006030	4-Stroke Light Commercial Pressure Washers	0.85	115
2265007005	4-Stroke Logging Equipment Chain Saws > 6 HP	0.70	303
2265007010	4-Stroke Logging Equipment Shredders > 6 HP	0.80	50
2265007015	4-Stroke Logging Equipment Skidders	0.70	350
2265007020	4-Stroke Logging Equipment Fellers/Bunchers	0.70	0
2265008005	4-Stroke Airport Support Equipment	0.56	681
2265009010	4-Stroke Other Underground Mining Equipment	0.80	260
2265010010	4-Stroke Other Oil Field Equipment	0.90	1104
2270001020	Diesel Snowmobiles (unused)	0.34	40
2270001030	Diesel All Terrain Vehicles/MC (unused)	0.42	0
2270001050	Diesel Golf Carts (unused)	0.49	1150
2270001060	Diesel Specialty Vehicle Carts	0.21	435
2270002003	Diesel Pavers	0.59	821
2270002006	Diesel Tampers/Rammers (unused)	0.43	460
2270002009	Diesel Plate Compactors	0.43	484
2270002012	Diesel Concrete Pavers (unused)	0.59	0
2270002015	Diesel Rollers	0.59	760
2270002018	Diesel Scrapers	0.59	914
2270002021	Diesel Paving Equipment	0.59	622
2270002024	Diesel Surfacing Equipment	0.59	561
2270002027	Diesel Signal Boards	0.43	535
2270002030	Diesel Trenchers	0.59	593
2270002033	Diesel Bore/Drill Rigs	0.43	466
2270002036	Diesel Excavators	0.59	1092
2270002039	Diesel Concrete/Industrial Saws	0.59	580
2270002042	Diesel Cement & Mortar Mixers	0.43	275
2270002045	Diesel Cranes	0.43	990
2270002048	Diesel Graders	0.59	962
2270002051	Diesel Off-highway Trucks	0.59	1641
2270002054	Diesel Crushing/Proc. Equipment	0.43	955
2270002057	Diesel Rough Terrain Forklifts	0.59	662
2270002060	Diesel Rubber Tire Loaders	0.59	761
2270002063	Diesel Rubber Tire Dozers	0.59	899
2270002066	Diesel Tractors/Loaders/Backhoes	0.21	1135

Load Factor and Activity Estimates in Draft NONROAD2004

SCC	Equipment Description	Load Factor (fraction of power)	Activity (hours/year)
2270002069	Diesel Crawler Tractors	0.59	936
2270002072	Diesel Skid Steer Loaders	0.21	818
2270002075	Diesel Off-Highway Tractors	0.59	855
2270002078	Diesel Dumpers/Tenders	0.21	566
2270002081	Diesel Other Construction Equipment	0.59	606
2270003010	Diesel Aerial Lifts	0.21	384
2270003020	Diesel Forklifts	0.59	1700
2270003030	Diesel Sweepers/Scrubbers	0.43	1220
2270003040	Diesel Other General Industrial Equipment	0.43	878
2270003050	Diesel Other Material Handling Equipment	0.21	421
2270003060	Diesel AC\Refrigeration	0.43	1341
2270003070	Diesel Terminal Tractors	0.59	1257
2270004010	Diesel Lawn mowers (Residential)	0.43	320
2270004011	Diesel Lawn mowers (Commerical)	0.43	320
2270004015	Diesel Rotary Tillers < 6 HP (Residential)	0.43	172
2270004016	Diesel Rotary Tillers < 6 HP (Commercial)	0.43	172
2270004020	Diesel Chain Saws < 6 HP (Residential)	0.43	70
2270004021	Diesel Chain Saws < 6 HP (Commercial)	0.43	70
2270004025	Diesel Trimmers/Edgers/Brush Cutters (Res.)	0.43	60
2270004026	Diesel Trimmers/Edgers/Brush Cutters (Comm.)	0.43	60
2270004030	Diesel Leafblowers/Vacuums (Residential)	0.43	120
2270004031	Diesel Leafblowers/Vacuums (Commercial)	0.43	120
2270004035	Diesel Snowblowers (Residential)	0.43	400
2270004036	Diesel Snowblowers (Commercial)	0.43	400
2270004040	Diesel Rear Engine Riding Mowers (Res.)	0.43	480
2270004041	Diesel Rear Engine Riding Mowers (Comm.)	0.43	480
2270004045	Diesel Front Mowers (Residential)	0.43	480
2270004046	Diesel Front Mowers (Commercial)	0.43	480
2270004050	Diesel Shredders < 6 HP (Residential)	0.43	120
2270004051	Diesel Shredders < 6 HP (Commercial)	0.43	120
2270004055	Diesel Lawn & Garden Tractors (Residential)	0.43	544
2270004056	Diesel Lawn & Garden Tractors (Commercial)	0.43	544
2270004060	Diesel Wood Splitters (Residential)	0.43	265
2270004061	Diesel Wood Splitters (Commercial)	0.43	265
2270004065	Diesel Chippers/Stump Grinders (Residential)	0.43	465
2270004066	Diesel Chippers/Stump Grinders (Commercial)	0.43	465
2270004070	Diesel Commercial Turf Equipment (Res.)	0.43	1068
2270004071	Diesel Commercial Turf Equipment (Comm.)	0.43	1068
2270004075	Diesel Other Lawn & Garden Equipment (Res.)	0.43	433
2270004076	Diesel Other Lawn & Garden Equipment (Comm.)	0.43	433
2270005010	Diesel 2-Wheel Tractors	0.59	544
2270005015	Diesel Agricultural Tractors	0.59	475
2270005020	Diesel Combines	0.59	150
2270005025	Diesel Balers	0.59	95
2270005030	Diesel Agricultural Mowers	0.59	363
2270005035	Diesel Sprayers	0.59	90
2270005040	Diesel Tillers > 6 HP	0.59	172
2270005045	Diesel Swathers	0.59	110
2270005050	Diesel Hydro Power Units	0.43	790
2270005055	Diesel Other Agricultural Equipment	0.59	381
2270005060	Diesel Irrigation Sets	0.43	749
2270006005	Diesel Light Commercial Generator Sets	0.43	338

Load Factor and Activity Estimates in Draft NONROAD2004

SCC	Equipment Description	Load Factor (fraction of power)	Activity (hours/year)
2270006010	Diesel Light Commercial Pumps	0.43	403
2270006015	Diesel Light Commercial Air Compressors	0.43	815
2270006020	Diesel Light Commercial Gas Compressors	0.43	8500
2270006025	Diesel Light Commercial Welders	0.21	643
2270006030	Diesel Light Commercial Pressure Washer	0.43	145
2270007005	Diesel Logging Equipment Chain Saws > 6 HP	0.59	70
2270007010	Diesel Logging Equipment Shredders > 6 HP	0.59	120
2270007015	Diesel Logging Equip Fell/Bunch/Skidders	0.59	1276
2270007020	Diesel Logging Equip Fell/Bunch (unused)	0.59	0
2270008005	Diesel Airport Support Equipment	0.59	732
2270009010	Diesel Other Underground Mining Equipment	0.21	1533
2270010010	Diesel Other Oil Field Equipment	0.43	1231
2267001020	LPG Snowmobiles	0.34	40
2267001050	LPG Golf Carts	0.46	1080
2267001060	LPG Specialty Vehicle Carts	0.58	65
2267002003	LPG Asphalt Pavers	0.66	392
2267002006	LPG Tampers/Rammers	0.55	160
2267002009	LPG Plate Compactors	0.55	166
2267002012	LPG Concrete Pavers	0.55	0
2267002015	LPG Rollers	0.62	621
2267002018	LPG Scrapers	0.70	540
2267002021	LPG Paving Equipment	0.59	175
2267002024	LPG Surfacing Equipment	0.49	488
2267002027	LPG Signal Boards	0.72	318
2267002030	LPG Trenchers	0.66	402
2267002033	LPG Bore/Drill Rigs	0.79	107
2267002036	LPG Excavators	0.59	378
2267002039	LPG Concrete/Industrial Saws	0.78	610
2267002042	LPG Cement & Mortar Mixers	0.59	84
2267002045	LPG Cranes	0.47	415
2267002048	LPG Graders	0.64	504
2267002051	LPG Off-highway Trucks	0.80	450
2267002054	LPG Crushing/Proc. Equipment	0.85	241
2267002057	LPG Rough Terrain Forklifts	0.63	413
2267002060	LPG Rubber Tire Loaders	0.71	512
2267002063	LPG Rubber Tire Dozers	0.75	900
2267002066	LPG Tractors/Loaders/Backhoes	0.48	870
2267002069	LPG Crawler Tractors	0.80	700
2267002072	LPG Skid Steer Loaders	0.58	310
2267002075	LPG Off-Highway Tractors	0.70	155
2267002078	LPG Dumpers/Tenders	0.41	127
2267002081	LPG Other Construction Equipment	0.48	371
2267003010	LPG Aerial Lifts	0.46	361
2267003020	LPG Forklifts	0.30	1800
2267003030	LPG Sweepers/Scrubbers	0.71	516
2267003040	LPG Other General Industrial Equipment	0.54	713
2267003050	LPG Other Material Handling Equipment	0.53	386
2267003060	LPG AC\Refrigeration	0.46	605
2267003070	LPG Terminal Tractors	0.78	827
2267004010	LPG Lawn mowers (Residential)	0.33	25
2267004011	LPG Lawn mowers (Commercial)	0.33	406
2267004015	LPG Rotary Tillers < 6 HP (Residential)	0.40	17

Load Factor and Activity Estimates in Draft NONROAD2004

SCC	Equipment Description	Load Factor (fraction of power)	Activity (hours/year)
2267004016	LPG Rotary Tillers < 6 HP (Commercial)	0.40	472
2267004020	LPG Chain Saws < 6 HP (Residential)	0.70	13
2267004021	LPG Chain Saws < 6 HP (Commercial)	0.70	303
2267004025	LPG Trimmers/Edgers/Brush Cutters (Res.)	0.91	9
2267004026	LPG Trimmers/Edgers/Brush Cutters (Comm.)	0.91	137
2267004030	LPG Leafblowers/Vacuums (Residential)	0.94	10
2267004031	LPG Leafblowers/Vacuums (Commercial)	0.94	282
2267004035	LPG Snowblowers (Residential)	0.35	8
2267004036	LPG Snowblowers (Commercial)	0.35	136
2267004040	LPG Rear Engine Riding Mowers (Residential)	0.38	36
2267004041	LPG Rear Engine Riding Mowers (Commercial)	0.38	569
2267004045	LPG Front Mowers (Residential)	0.65	86
2267004046	LPG Front Mowers (Commercial)	0.65	86
2267004050	LPG Shredders < 6 HP (Residential)	0.80	50
2267004051	LPG Shredders < 6 HP (Commercial)	0.80	50
2267004055	LPG Lawn & Garden Tractors (Residential)	0.44	45
2267004056	LPG Lawn & Garden Tractors (Commercial)	0.44	721
2267004060	LPG Wood Splitters (Residential)	0.69	76
2267004061	LPG Wood Splitters (Commercial)	0.69	76
2267004065	LPG Chippers/Stump Grinders (Residential)	0.78	488
2267004066	LPG Chippers/Stump Grinders (Commercial)	0.78	488
2267004070	LPG Commercial Turf Equipment (Residential)	0.60	682
2267004071	LPG Commercial Turf Equipment (Commercial)	0.60	682
2267004075	LPG Other Lawn & Garden Equipment (Res.)	0.58	61
2267004076	LPG Other Lawn & Garden Equipment (Comm.)	0.58	61
2267005010	LPG 2-Wheel Tractors	0.62	286
2267005015	LPG Agricultural Tractors	0.62	550
2267005020	LPG Combines	0.74	125
2267005025	LPG Balers	0.62	68
2267005030	LPG Agricultural Mowers	0.48	175
2267005035	LPG Sprayers	0.65	80
2267005040	LPG Tillers > 6 HP	0.71	43
2267005045	LPG Swathers	0.52	95
2267005050	LPG Hydro Power Units	0.56	450
2267005055	LPG Other Agricultural Equipment	0.55	124
2267005060	LPG Irrigation Sets	0.60	716
2267006005	LPG Light Commercial Generator Sets	0.68	115
2267006010	LPG Light Commercial Pumps	0.69	221
2267006015	LPG Light Commercial Air Compressors	0.56	484
2267006020	LPG Light Commercial Gas Compressors	0.85	6000
2267006025	LPG Light Commercial Welders	0.68	408
2267006030	LPG Light Commercial Pressure Washers	0.85	115
2267007005	LPG Logging Equipment Chain Saws > 6 HP	0.70	303
2267007010	LPG Logging Equipment Shredders > 6 HP	0.80	50
2267007015	LPG Logging Equipment Skidders	0.70	350
2267007020	LPG Logging Equipment Fellers/Bunchers	0.70	0
2267008005	LPG Airport Support Equipment	0.56	681
2267009010	LPG Other Underground Mining Equipment	0.80	260
2267010010	LPG Other Oil Field Equipment	0.90	1104
2268001020	CNG Snowmobiles	0.34	40
2268001050	CNG Golf Carts	0.46	1080
2268001060	CNG Specialty Vehicle Carts	0.58	65

Load Factor and Activity Estimates in Draft NONROAD2004

SCC	Equipment Description	Load Factor (fraction of power)	Activity (hours/year)
2268002003	CNG Asphalt Pavers	0.66	392
2268002006	CNG Tampers/Rammers	0.55	160
2268002009	CNG Plate Compactors	0.55	166
2268002012	CNG Concrete Pavers	0.55	0
2268002015	CNG Rollers	0.62	621
2268002018	CNG Scrapers	0.70	540
2268002021	CNG Paving Equipment	0.59	175
2268002024	CNG Surfacing Equipment	0.49	488
2268002027	CNG Signal Boards	0.72	318
2268002030	CNG Trenchers	0.66	402
2268002033	CNG Bore/Drill Rigs	0.79	107
2268002036	CNG Excavators	0.53	378
2268002039	CNG Concrete/Industrial Saws	0.78	610
2268002042	CNG Cement & Mortar Mixers	0.59	84
2268002045	CNG Cranes	0.47	415
2268002048	CNG Graders	0.64	504
2268002051	CNG Off-highway Trucks	0.80	450
2268002054	CNG Crushing/Proc. Equipment	0.85	241
2268002057	CNG Rough Terrain Forklifts	0.63	413
2268002060	CNG Rubber Tire Loaders	0.71	512
2268002063	CNG Rubber Tire Dozers	0.75	900
2268002066	CNG Tractors/Loaders/Backhoes	0.48	870
2268002069	CNG Crawler Tractors	0.80	700
2268002072	CNG Skid Steer Loaders	0.58	310
2268002075	CNG Off-Highway Tractors	0.70	155
2268002078	CNG Dumpers/Tenders	0.41	127
2268002081	CNG Other Construction Equipment	0.48	371
2268003010	CNG Aerial Lifts	0.46	361
2268003020	CNG Forklifts	0.30	1800
2268003030	CNG Sweepers/Scrubbers	0.71	516
2268003040	CNG Other General Industrial Equipment	0.54	713
2268003050	CNG Other Material Handling Equipment	0.53	386
2268003060	CNG AC\Refrigeration	0.46	605
2268003070	CNG Terminal Tractors	0.78	827
2268004010	CNG Lawn mowers (Residential)	0.33	25
2268004011	CNG Lawn mowers (Commercial)	0.33	406
2268004015	CNG Rotary Tillers < 6 HP (Residential)	0.40	17
2268004016	CNG Rotary Tillers < 6 HP (Commercial)	0.40	472
2268004020	CNG Chain Saws < 6 HP (Residential)	0.70	13
2268004021	CNG Chain Saws < 6 HP (Commercial)	0.70	303
2268004025	CNG Trimmers/Edgers/Brush Cutters (Res.)	0.91	9
2268004026	CNG Trimmers/Edgers/Brush Cutters (Comm.)	0.91	137
2268004030	CNG Leafblowers/Vacuums (Residential)	0.94	10
2268004031	CNG Leafblowers/Vacuums (Commercial)	0.94	282
2268004035	CNG Snowblowers (Residential)	0.35	8
2268004036	CNG Snowblowers (Commercial)	0.35	136
2268004040	CNG Rear Engine Riding Mowers (Residential)	0.38	36
2268004041	CNG Rear Engine Riding Mowers (Commercial)	0.38	569
2268004045	CNG Front Mowers (Residential)	0.65	86
2268004046	CNG Front Mowers (Commercial)	0.65	86
2268004050	CNG Shredders < 6 HP (Residential)	0.80	50
2268004051	CNG Shredders < 6 HP (Commercial)	0.80	50

Load Factor and Activity Estimates in Draft NONROAD2004

SCC	Equipment Description	Load Factor (fraction of power)	Activity (hours/year)
2268004055	CNG Lawn & Garden Tractors (Residential)	0.44	45
2268004056	CNG Lawn & Garden Tractors (Commercial)	0.44	721
2268004060	CNG Wood Splitters (Residential)	0.69	76
2268004061	CNG Wood Splitters (Commercial)	0.69	76
2268004065	CNG Chippers/Stump Grinders (Residential)	0.78	488
2268004066	CNG Chippers/Stump Grinders (Commercial)	0.78	488
2268004070	CNG Commercial Turf Equipment (Residential)	0.60	682
2268004071	CNG Commercial Turf Equipment (Commercial)	0.60	682
2268004075	CNG Other Lawn & Garden Equipment (Res.)	0.58	61
2268004076	CNG Other Lawn & Garden Equipment (Comm.)	0.58	61
2268005010	CNG 2-Wheel Tractors	0.62	286
2268005015	CNG Agricultural Tractors	0.62	550
2268005020	CNG Combines	0.74	125
2268005025	CNG Balers	0.62	68
2268005030	CNG Agricultural Mowers	0.48	175
2268005035	CNG Sprayers	0.65	80
2268005040	CNG Tillers > 6 HP	0.71	43
2268005045	CNG Swathers	0.52	95
2268005050	CNG Hydro Power Units	0.56	450
2268005055	CNG Other Agricultural Equipment	0.55	124
2268005060	CNG Irrigation Sets	0.60	716
2268006005	CNG Light Commercial Generator Sets	0.68	115
2268006010	CNG Light Commercial Pumps	0.69	221
2268006015	CNG Light Commercial Air Compressors	0.56	484
2268006020	CNG Light Commercial Gas Compressors	0.85	6000
2268006025	CNG Light Commercial Welders	0.68	408
2268006030	CNG Light Commercial Pressure Washers	0.85	115
2268007005	CNG Logging Equipment Chain Saws > 6 HP	0.70	303
2268007010	CNG Logging Equipment Shredders > 6 HP	0.80	50
2268007015	CNG Logging Equipment Skidders	0.70	350
2268007020	CNG Logging Equipment Fellers/Bunchers	0.70	0
2268008005	CNG Airport Support Equipment	0.56	681
2268009010	CNG Other Underground Mining Equipment	0.80	260
2268010010	CNG Other Oil Field Equipment	0.90	1104
2282005010	2-Stroke Outboards	0.21	34.8
2282005015	2-Stroke Personal Watercraft	0.21	77.3
2282010005	4-Stroke Inboards	0.21	47.6
2282020005	Diesel Inboards	0.43	200
2282020010	Diesel Outboards	0.43	150
2282020025	Diesel Sailboat Aux. Outboard (unused)	0.43	68
2285002015	Diesel Railway Maintenance	0.21	943
2285003015	2-Stroke Gasoline Railway Maintenance	0.62	184
2285004015	4-Stroke Gasoline Railway Maintenance	0.62	184
2285006015	LPG Railway Maintenance	0.62	184
2285008015	CNG Railway Maintenance	0.62	184

* Activities for off-road motorcycles and all terrain vehicles are in units of miles per year.

Appendix B

Documentation of the Median Life Values in the California OFFROAD Model

DOCUMENTATION OF DIESEL ENGINE LIFE VALUES USED IN THE ARB OFF-HIGHWAY MODEL

Prepared for:
OFFICE OF MOBILE SOURCES
ENVIRONMENTAL PROTECTION AGENCY
Ann Arbor, MI

EPA Purchase Order: 1A-0462-NASX

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1. BACKGROUND

In the 1992-1993 time frame, EEA developed a model for the California Air Resources Board (ARB). The model estimates emission inventory from off-highway mobile sources of all types. The model's emissions calculations require tracking of the population of each equipment type/engine combination by vintage. The vintage distribution of any particular type of off-highway equipment and engine type is determined from a scrappage model that requires engine useful life as an input. The same engine type can be utilized across a number of equipment types that place different loads on the engine. The scrappage model is constructed in a manner that allows useful life for a given equipment type to vary based on the simple formulation that engine life in application "i" is given by:

$$(\text{Engine Life})_i = \frac{(\text{Engine Life})_{\text{full load}}}{(\text{Load Factor})_i}$$

Hence, engine life in a particular application is inversely proportional to the average load factor, and engine life at full load is specified within the model.

Engines were categorized by fuel type, horsepower range and engine cycle (two- versus four-stroke). At this subcategory level, the population of engines was assumed to be homogeneous, based on the fact that engines competing in the marketplace for the same market segment offer competitive durability. The development of specific engine life estimates for each engine subcategory is described in this memorandum.

It should be noted that the ARB Off-Highway Model is the first of its kind, and was developed in a period when virtually all information had to be obtained from original sources and very few were available publicly. Given the wide range of engines and equipment available in the off-highway market, a number of simplifying assumptions had to be made. Some of the data and inputs in the model are potentially outdated, based on new research and testing conducted in the last decade years following its development.

Second, it should be noted that the single most important source of data for equipment type, population and useful life was Power Systems Research (PSR), that has a proprietary database on off-highway equipment sales, population and scrappage. While the Power Systems Research data was the single largest and most unified source of data, EEA conducted a detailed assessment of PSR populations and sales data provided by comparing these data with data from other sources. In many instances, we found PSR data could not be justified, and EEA changed the data based on inputs from industry associations and engine manufacturers. In particular, the PSR engine life data appeared to be most incorrect for smaller engines.

This memo first describes the PSR data and specifically identifies areas where our comparison indicated that PSR was likely in potential error. Second, EEA describes the methodology by which we derived other data that were judged more appropriate for the model.

2. PSR DATA DESCRIPTION

Data purchased from PSR included detailed breakouts of California off-highway populations by engine type, fuel type and horsepower range. PSR also provide a separate data file on the mean engine life by engine model in hours at rated load.

The PSR methodology for estimating population is based on sales and scrappage. PSR obtains sales data from a number of proprietary sources including manufacturers and dealers. Nationwide sales are allocated to regions based on survey data and dealer based information. Scrappage is estimated as a function of vintage and engine mean life. Central to the estimates is a non-dimensional survival curve that provides survival rates in percent on the Y-axis against fraction of engine life used. The curve is S-shape, and starts at one at zero engine life used. At engine life equal to one, the survival rate is fifty percent, and at engine life equal to two, survival rate is zero. Hence, the engine life value is the point where half of all engine are scrapped.

Engine life in a particular application is engine life at rated load divided by the load factor on a typical duty cycle for the application. PSR has developed load factors for each application although we have no explicit understanding of how the load factors were developed. Engine life at rated load is determined by a proprietary formula that related life to bore/stroke, design type and specific output. The formula itself is proprietary and undocumented. Nevertheless, we obtained a detailed database on life by engine model to allow us to assess the formula.

Population is derived from sales with the formula:

$$\text{Population} = \sum_i \text{Sales}_i \, x \, \text{Survival Rate}_i$$

summed over i = 0 to twice the engine life in the application. Engine life in years for an application is given by:

$$\frac{\text{Engine Life at Rated HP (hours)}}{\text{Load Factor } x \text{ Use (hours/year)}}$$

$$\text{Population} \cong \text{Average Sales } x \text{ engine life (years)}$$

For equipment types that have no time trend in sales, we can estimate population using:

We utilized the above formula in several instances to estimate populations from available sales data. In many cases, sales of off –highway equipment have shown no growth trend over a long period, so that the above formula can provide a reasonable estimate of population.

3. EEA ANALYSIS OF THE PSR DATA

A very detailed comparison of PSR population estimates by equipment category was undertaken. Briefing charts presented to the ARB documenting all the comparisons have been provided to EPA, and only the key data and major conclusions are presented here.

In lawn and garden equipment, PSR population data from most non-commercial equipment such as chain saws and lawn mowers were a factor of ten higher than estimates from the industry or estimates based on (sales *x* useful life). For commercial equipment, PSR's estimates were more reasonable and comparable to other estimates. However, most lawn and garden equipment are powered by gasoline engines. For recreational equipment such as motorcycles, snowmobiles and ATVs, PSR estimates were very low relative to other estimates. This category also has no diesel powered equipment.

For industrial equipment, PSR totals across all fuel types and horsepower categories were comparable to estimates from industry associations. However, the gasoline (and LPG)-to-diesel split was very different. Diesel engine equipment populations were significantly over-estimated by PSR (by a factor of three to four), while gasoline engine equipment populations were underestimated significantly. Similar trends were also found for transport refrigeration units, and diesel airport ground support equipment. These equipment typically are powered by diesel engines in the 25 to 100 HP range.

No validation of PSR data could be done for light commercial equipment such as generator sets, pumps and compressors. One study by Booz-Allen Hamilton suggested PSR estimates for diesels were incorrect by more than an order of magnitude, although the Booz-Allen numbers for diesels are not well documented. Equipment in this category utilize diesel engines under 50 HP.

PSR population data for agricultural tractors (typically in the 50 to 150 HP range) were also significantly higher than estimates from the Agricultural Census and sales based estimates. The differences were in the range of 50 to 150 percent.

Finally PSR estimates of populations for construction equipment were much closer to those derived from sales or industry data on populations. These equipment typically use diesel engines over 200 HP. PSR estimates were higher than those from industry, but the margin of difference was not large, ranging from 10 to 30 percent.

As a result of this comparison, we concluded that PSR's diesel engine life estimates appeared to be optimistic, and the level of optimism increased with decreasing HP. It appeared that for small diesel engines (less than 50 HP), the PSR life estimates were potentially in serious error. As a result of the population analysis, we requested and obtained the detailed PSR life data by engine model. Due to its proprietary nature, only aggregate statistics are provided in this report. Table 1 provides the PSR useful life data after filtering the data for zeroes and blanks. (There were only a very small number of such cases, including one obvious typographical error). As shown in Table 1, the average engine life by HP range declines with increasing horsepower, although the decline is not large relative the distribution of values within engine HP range. For example, all engines in the 25 to 750 HP range have an average life of 10,700±1300 hours.

Based on our knowledge of engines and their applications, the declining trend as well as the absolute values appeared incorrect, especially for the smaller engines.

Since the variation of useful life with HP ranges were larger than the changes to the averages across HP ranges, we use investigated the data more thoroughly. The detailed data showed that engine life appeared to be a stronger function of its aspiration (turbocharged or naturally aspirated) than its displacement or power output. Within naturally aspirated engines, there was a trend to increasing average useful life with size and horsepower, ranging from 12,000 hours for small engines to 18,000 hours for the largest engines. (A few engines had even higher useful life numbers, but it was not clear why). However, a given engine model's useful life was found to be inversely proportional to its horsepower output. For example, most of the larger engines are offered in naturally aspirated, turbocharged and aftercooled models at a variety of HP ratings. The PSR model simply scales the life in exact inverse proportion to the HP rating.

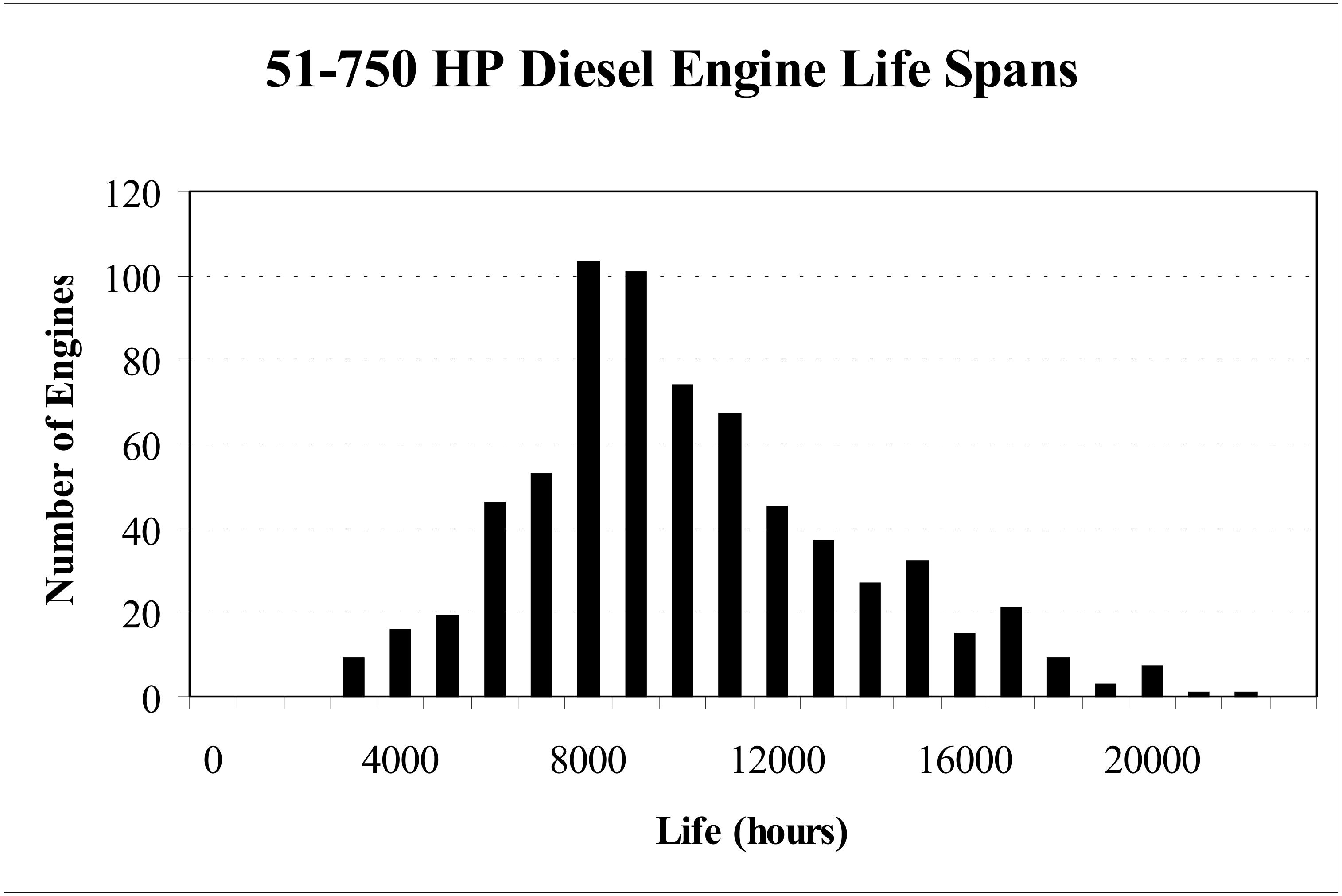
Figure 1 shows the distribution of useful life ratings from engines in the 50 to 750 HP range. Most naturally aspirated engine are in the upper end of the life range, turbocharged engines in the middle of the range and turbocharged/aftercooled engines in the lower end of the useful life range, in concert with their increasing specific output. Two stroke engine, with specific output almost twice the specific output of four-stroke engines, had the lowest useful life values. The decline in average useful life with increasing HP in Table 1 is due to the fact that a larger proportion of high HP engines are turbocharged, or turbocharged and aftercooled, but is not related to the larger engine size.

TABLE 1
PSR DATA ON ENGINE LIFE AT RATED LOAD
(hours)

HP Range	Sample Size	Average*	Maximum	Minimum	Standard Deviation
2.1 – 15	104	13,704	29,713	5,579	1,705
15.1 – 25	88	12,364	16,062	4,178	2,404
25.1 – 50	118	11,315	23,625	5,406	3,463
50.1 – 120	241	10,331	22,627	4,469	3,463
120.1 – 175	106	11,994	31,171	3,910	4,135
175.1 – 250	17	11,038	20,847	3,029	3,907
250.1 – 500	189	10,076	19,452	4,464	2,695
500.1 – 750	36	9,490	18,968	3,927	2,986
750+	27	8,264	18,654	5,070	2,818

*** Average across all engine models without sales weighting.**

Figure 1


51-750 HP Diesel Engine Life Spans
Number of Engines
0
20
40
60
80
100
120
0
4000
8000
12000
16000
20000
Life (hours)

EEA's knowledge of engines suggested that the PSR approach was incorrect. For example, Detroit Diesel's two-stroke engines do not have the reputation for wearing out twice as fast as other competitive four-stroke engines in truck applications. In addition, we are generally unaware of any major decrease in life for turbocharged and aftercooled engines in the on-highway segment relative to turbocharged or naturally aspirated engines. Hence, EEA decided to specify the useful life data independently of PSR data.

4. USEFUL LIFE VALUES IN THE MODEL

EEA took a three-step approach to determining the correct useful life, as follows. First, we identified popular (high sales) engines within each horsepower category. Second, we contacted a subset of the engine manufacturers of these popular engines to obtain their views on engine life. Third, we developed engine life based on a combination of manufacturer comments and available data from on-highway engines.

The identification of popular engine models by horsepower range was based on data developed under earlier studies for ARB by EEA. Table 2 shows the data for diesel engines above 50 HP. (The horsepower ranges in the table do not exactly correspond to those in the model, since ARB requested some changes in the ranges towards the end of the project).

In general, the four major on-highway diesel engine manufacturers (Cummins, Caterpillar, Detroit Diesel and IH, now Navistar) offer versions of their on-highway products for the off-highway market. In addition, John Deere is the only the other major domestic engine manufacturer that sells engines directed almost completely to the off-highway market. Kubota, Deutz and Perkins are the major import engine brands in the market for engines over 50 HP.

In the 50–120 HP market, sales are dominated by four-cylinder versions of six-cylinder on-highway medium heavy-duty engines such as the Cummins B and C series, the Caterpillar 1.1L/cylinder series and the 3200 series, and Detroit Diesel's 53 Series engines. In the next higher range of 120 to 175 HP, on-highway medium-heavy duty engines and some naturally aspirated versions of heavy-heavy duty engines dominate sales. Above 175 HP, a majority of engines are derivatives of heavy-heavy duty on-highway engines, except at the highest horsepower end, over 500 HP. At these high HP levels, some specialized engines such as Caterpillar's 3500 series, DDC's 149 series and Cummins KT series are available and are not generally sold in the on-highway market. Sales of engines in the very high HP categories are quite small.

In the lower horsepower ranges below 50 HP, two types of engines dominate sales. In industrial tractors and small airport ground support equipment, derated versions of passenger car diesel engines (from manufacturers like Perkins, VW, Isuzu and Toyota) are utilized. Such engines are typically rated from 30 to 50 HP.

TABLE 2
1991 ENGINE MODELS BY HORSEPOWER CATEGORY

Manufacturer	50 to120 HP	120 to 250 HP	250 to 500 HP	Over 500 HP
Caterpillar	3114T 3204NA 3304NA	3116T 3208NA 3306NA	3306T/TA 3406T/TA 3408T/TA	3412T/TA 3408TA All 3500 series
Cummins	4A2.3 6A3.4 4B3.9	6B5.9T/TA 6C8.3T/TA	L-10T/TA NTC-855T/TA	KT-19 VT-28 KV-38
Detroit Diesel	3-53N/T 4-53N 8.2L N	3-53T 4-53T 6-71N	6-71T/TA 8-71T/TA 6-92N/T/TA	8-92T/TA 12-92T/TA All 149 series
Deere	3-179N/T 4-239N/T 4-276N/T	6-359T/TA 6-414T/TA 6-466T/TA	6-619T/TA 8-955T/TA	
IH	D-239N/T D-360N	D-360T D-466N/T/TA		
Komatsu	4D-94N/T 4D-95N/T 4D-105N	4D-130N/T 6D-95N/T 6D-105N/T	6D-125T/TA 6D-140N/T 6D-155N/T	6D-170T/TA 8V-170T/TA 12V170T/TA
Deutz	FL912N/T FL913N/T	FL913T/TA FL413N/T	FL413T/TA FL513T/TA	
Perkins	3-153N/T 4-236N/T	6-354N/T 8-540N/T	6-734T/TA 8-1062T/TA	

N is for naturally aspirated, T for turbocharged and A for aftercooled.

Small two- or three-cylinder engines from manufacturers such as Kubota, Yanmar, Onan, and Teledyne-Wisconsin are utilized in the 15–40 HP range and are a mix of air cooled and water-cooled engines. Engines under 15 HP are also offered by these same manufacturers and are mostly single-cylinder air-cooled diesels. Most of these engines find application is light commercial equipment.

Useful life estimates for engines over 50 HP were based on information from heavy-duty diesel engine manufacturers. EEA spoke with representatives from Caterpillar, Cummins, Navistar and Detroit-Diesel.[3] All were questions about the:

- correctness of the PSR algorithm of scaling life by load factor, and by specific output;
- typical useful life in on-highway applications;
- comparability to useful life in off-highway applications.

Information obtained was subjective and experienced based, but no hard data was provided by manufacturers.

On PSR's useful life algorithms, manufacturers agreed that load factor was inversely related to engine life but cautioned that this relationship could not hold over the entire range of load factors from zero to one. They believed it would overestimate life at very light load factors and underestimate life as load factor approached one. They did not agree, however, with PSR's method of derating life at full load inversely with specific output across all aspiration types. While suggesting that there is variation in life with increasing output, manufacturers also stated that many components are upgraded in turbocharged engines relative to their naturally aspirated counterparts, and that warranty protection is the same for all engine types. They also pointed to the evidence that inspite of increasing specific output in the late-1980s and early 1990s, they had not observed any significant change in useful life.

For heavy-heavy duty on-road engines, most manufacturers agreed that engine life (defined as the point when the engine is removed from the truck for a rebuild) for an over-the-road application, i.e., mostly highway miles, was in the 700,000 to 750,000 miles range. Note that this referred to engines from the last decade, as we understand that current engines last up to a million miles. Manufacturers suggested that miles could be converted to hours by assuming that most mileage was accumulated at highway speeds of, say, 60 mph as an average. Manufacturers also generally agreed that EPA's original durability finding that medium-heavy duty engines have two-thirds the life of heavy-heavy duty engines was a reasonable estimate.

In order to develop useful life at rated HP, a load factor corresponding to 60 MPH operation is required. Simulation models such as "TCAPE" show that an 80,000 lb. GVW truck cruising on a level road at 60 mph requires 210 to 220 HP. A typical engine rated HP for the application is 350 HP to 375 HP, suggesting a load factor of 0.6. It is also known that trucks are geared to operate at close to the best bsfc point at cruising speed. The best bsfc point

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[3]* contact names are listed in Appendix A.

usually occurs at 70 percent of peak torque and close to the peak torque RPM which is about 70 percent of rated RPM. Peak torque is usually about 20 percent higher than trque at rated RPM. Since:

Rated HP	=	$(\text{Torque})_R \, x \, (\text{RPM})_R$

where subscript R is for rated values, we can calculate

Peak Torque	@	$1.2 \, x \, (\text{Torque})_R$
RPM @ Peak Torque	=	$0.7 \, x \, (\text{RPM})_R$
Cruise Point	0	0.7 *x* Peak Torque *x* RPM @ Peak Torque
	=	$0.7 \, x \, 1.2 \text{ x } (\text{Torque})_R \, x \, 0.7 \, x \, (\text{RPM})_R$
	@	$0.6 \, x \, (\text{Torque})_R \, x \, (\text{RPM})_R$

Hence, the cruise point calculation also implies a load factor of about 0.6.

From this, we can derive a life at rated power in hours:

$$\text{Life} = \frac{700{,}000 \text{ miles}}{60 \text{ mph}} \; x \; \text{Load Factor}$$

$$= \; 7000 \text{ hours}$$

Manufacturers had only subjective opinions for the life in off-road use, and suggested some adjustment factor for “rough-duty” conditions. These suggestions were to reduce the on-highway life by 10 to 20 percent, and we selected 15 percent as an approximate average. Adjusting the on-highway life of 7000 hours by 15 percent provided a useful life rating for off-highway engines of 6000 hours. Using the fact that medium duty engines offered two-thirds the life of heavy-heavy duty engines, we estimated their life at 4000 hours.

Useful life for smaller engines (under 50 HP) was based on less information. EEA contacted representatives from Kubota, Yanmar, Perkins and VW to obtain information on diesel engine useful life but they had no specific information on hours. One manufacturer suggested using information on forklift truck scrappage, but we found that the Industrial Truck Association only has an average life for all fork-lifts (gasoline and diesel), and the data was not directly useful. Several members commented that the engines were physically similar in design to light-duty automotive diesels, which was the basis for our estimate of life. Because of the very low load factor (around 0.1) in typical automotive use, a mileage based estimate leads to very long useful life (>10,000 hours). Rather, we utilized the fact that small light duty (passenger car) diesel have durability comparable to gasoline engines of similar displacement. Data from auto-manufacturers show that a typical wide open throttle durability requirement for gasoline four-cylinder engines is about 2500 hours. This value was used for diesel engines in the 15 to 50 HP range. No adjustments were made for off-highway use, since these engines are typically not used in rough duty applications.

Diesels in the under 15 HP category are typically small single cylinder air-cooled engines. Again, no specific life figures were obtained from manufacturers. However, they believed that durability was lower than the value of the larger water cooled multi-cylinder units in the

15-50 HP category. EEA selected 1250 hours as a plausible value, but recognize that this is not supported by any data. It also reflects the fact that it is about ten percent of PSR's estimate. Given that PSR estimates of small diesel populations are over ten times the estimates of other organizations, the value appears to be a reasonable estimate.

5. SUMMARY

Based on detailed comparison of populations, it appeared that PSR overestimates diesel equipment populations, with the level of overestimate increasing from the 20 percent range for the largest diesels to over 1000 percent for the smallest diesels.

A detailed examination of their data on engine useful life at rated load showed counterintuitive estimates, with the smallest diesel engine having substantially higher useful life relative to the largest diesels. These estimate were traced to assumptions about the relationship of engine life to specific output (HP/liter) that EEA believes are incorrect.

EEA developed its own estimates by comparison with on-road engines useful life, where engine types in each HP range were matched with on-road counterparts. Data for engines under 50 HP, however, was unavailable and based largely on subjective comments from the manufacturers. The ratio of EEA useful life estimates to PSR estimates for each HP category is quite similar to the ratio of equipment population estimates from other sources to PSR's equipment population estimates, suggesting that EEA useful life estimates are reasonable.

APPENDIX A
LIST OF CONTACTS

Caterpillar	Don Dowdall
Cummins	Mike Brand
Navistar (IH)	Ed Sienecke
Detroit Diesel	John Fisher
Kubota	Kevin Kokrda
Yanmar	Norman Weir and Kozuhiro Nomura
Perkins	P.A. Harrison (England)
VW	Wolfgang Groth