United States Environmental Protection Agency
Air and Radiation
EPA420-P-02-017
June 2002
NR-007a

Calculation of Age Distributions in the Nonroad Model: Growth and Scrappage

Printed on Recycled Paper

EPA420-P-02-017
June 2002

Calculation of Age Distributions in the Nonroad Model: Growth and Scrappage

NR-007a

Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

Calculation of Age Distributions in the Nonroad Model:
Growth and Scrappage

Report No. NR-007a
June 10, 2002

Assessment and Standards Division
EPA, Office of Transportation and Air Quality

Introduction

The Draft NONROAD2002 version of the US EPA nonroad engine emission inventory model ("NONROAD") calculates nonroad equipment populations by age (i.e., an age distribution) for given equipment types and scenario years. This calculation is necessary for the model to account for factors which affect nonroad emissions over time as the in-use fleet ages and turns over to newer equipment, including emissions deterioration, new emissions standards, technology changes, and changes in equipment population resulting from sales growth trends.

The NONROAD model calculates equipment age distributions for each horsepower range of each equipment type based on the median life (hours at full load), activity (hours of use per year), load factor, and current growth rate for that equipment, combined with the model's generalized scrappage function. Age distribution refers to the fractions of a given equipment's population that are one, two, three, etc., years old in a given target year. This age distribution is treated as constant regardless of the target calendar year being evaluated, as described in more detail below. This methodology differs from the previous versions of NONROAD, which attempted to calculate age distributions for future years by stepping through each year between the base year and future evaluation year, calculating equipment populations and scrappage for each model year of equipment still in service, and the necessary equipment sales to meet the projected population (see NR-007, 1998) [1].

Following are descriptions of the NONROAD model calculation methodology for population growth and equipment age distribution, followed by detailed descriptions of the relevant model inputs and a glossary that defines the key terms used. Terms contained in the glossary are italicized the first time they appear in this report subsequent to this introduction.

Methodology

The NONROAD model calculates equipment populations and the *age distribution* of those populations. The methods used by the model to perform these calculations are described below. Basically, the model uses the *population growth rate* to project equipment populations from a *base year* to the desired evaluation year. Then it applies the age distribution to that equipment population to estimate the number of units of each age (model year) back to two times the median life in years, up to a maximum of 50 years.

Population Growth: Growth Rates and Projected Populations

The NONROAD model projects equipment populations in past and future years (before and after the input population base year) by applying a growth rate to the base year equipment population. This growth rate is calculated by determining the linear *annual growth rate* in equipment population between 1989 and 1996, as reported by Power Systems Research (PSR). This approach is discussed more fully in EPA technical report "Nonroad Engine Growth Estimates" (NR-008b) [2]. Other than certain exceptions, such as All Terrain Vehicles (ATV's), the model assumes that the population growth rate remains constant for all years before and after the base year.

The growth rates are used to generate the growth index values that are contained in the growth input data file (nation.grw), which is more completely described in the Inputs section below. The model uses linear interpolation between these growth indexes to calculate any index for target years between the input growth index years. For target years prior to the earliest growth index year or after the latest growth index year the model uses linear extrapolation from the two closest growth index inputs. The target year *total equipment population* for each horsepower range of each equipment type is then calculated by multiplying the base year population by the ratio of the target year growth index to the base year growth index.

Age Distribution: Scrappage Curve Adjusted for Growth

The NONROAD model assumes a constant age distribution for each power range of each equipment type. E.g., according to the model the percentage of 50-100 hp diesel agricultural tractors that are ten years old in the year 2000 is the same as the percentage that are ten years old in 2020. This age distribution algorithm is essentially the same as what was used in previous versions of the NONROAD model for the base year and earlier years and for negative growth in future years. But the model now also uses that same methodology in cases of positive growth in future years, rather than using a more complex method that stepped through each future year's scrappage and calculated the sales that would be required to achieve the predicted population. Also, instead of directly using the input scrappage curve values (percent scrapped versus percentage of median life used) from the growth data file as an age distribution curve, the model now uses a modified version of those values that accounts for growth. Thus, an equipment type that has zero growth would have an age distribution that exactly matches the input scrappage curve (see Figure 1). But if there is positive growth, the age distribution will be skewed more toward newer engines (Figures 2, 3, and 4).

The methodology can be summarized as follows: For each SCC use the linear growth from the first period supplied in the growth input file (e.g., 1996 - 1998) plus the input scrappage curve to build a modified "scrappage curve" that is actually a customized age distribution curve for that particular growth rate. Apply this age distribution curve to all calendar years including the base year, earlier calendar years, and all future calendar years.

Following is a more detailed step-by-step technical description of the methodology used in NONROAD:

1. For each SCC, read the first two growth entries in the growth input data file and calculate the linear annual growth rate relative to the first (earlier) year's value. For most equipment types, these are currently the entries for calendar years 1996 and 1998, where the 1996 entry is always arbitrarily set to 1,000, and the year 1998 entry is 1,000 plus whatever relative growth is assumed for that category. E.g., for diesel farm equipment, the year 1998 entry is currently 1,063, indicating a linear growth of (1,063-1,000)/1,000/2 yrs = 3.15% per year relative to 1996.

2. For each SCC, create a temporary array the size of MXSCRP, which is currently a 50 element array, and initialize it with a contrived "sales ratio history" using the growth rate from Step 1. I.e., for a 3.0% linear growth rate the first (earliest) entry would be 1.00, the second would be 1.03, the third would be 1.06, etc., increasing by 0.03 each time. An example of the results of this and subsequent calculation steps, using 3.0% linear growth, is provided in the appendix of this report. This ratio sales history is labeled as "Orig. Sales Ratio" in the appendix.

3. Multiply each value in this temporary array by the corresponding survival fraction (= 1 - percent scrapped) from the scrappage array (see Table 1 below) to generate a value for the relative number of units surviving in the target year. This is labeled as "Surviving Pop Ratio" in the appendix. Replace the original temporary array value with this new value.

4. Divide each value in the temporary array by the sum of all of the array values, effectively turning it into an age distribution. Replace each original temporary array value with the new value. This is labeled as "Age Distrib." in the appendix.

5. Normalize the values in the temporary array to represent a new version of percent scrapped that includes growth. An example of this calculation is shown below, and the results appear as the column labeled "Normalized as % Scrapped" in the appendix.

Percent "Scrapped" = 100 * (1 - (MYfrac/MaxMYfrac))

where:

Percent "Scrapped" = the percent reduction from the initial population (sales) for each model year. "Scrapped" is in quotes because in this use it doesn't actually mean percent scrapped, but rather a relative measurement of scrappage with respect to the other model years.

MYfrac = the surviving population of the model year of interest divided by the sum of all model years' surviving populations in the calendar year being evaluated.

MaxMYfrac = the maximum MYfrac of all the model years for the equipment type being considered.

6. Use this new temporary array in place of the scrappage curve values to generate populations for all past model years in whatever calendar year is being modeled (past, base, or future years).

Figure 1 Input Scrappage Curve (no growth)

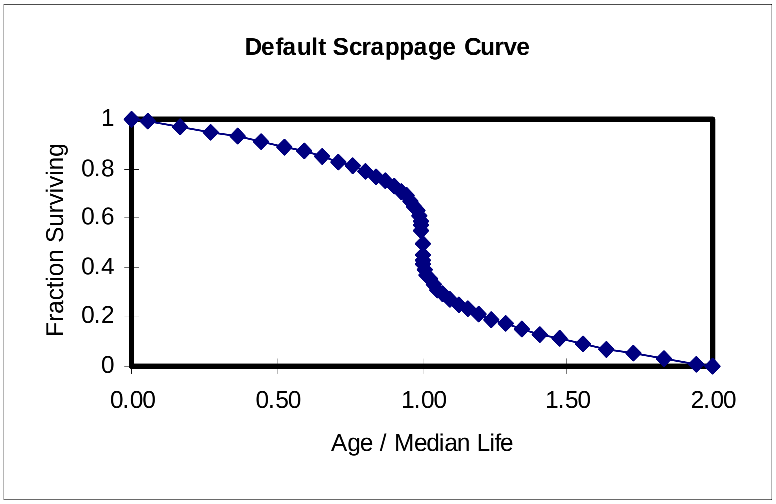


Figure 2 Age Distribution (with growth)

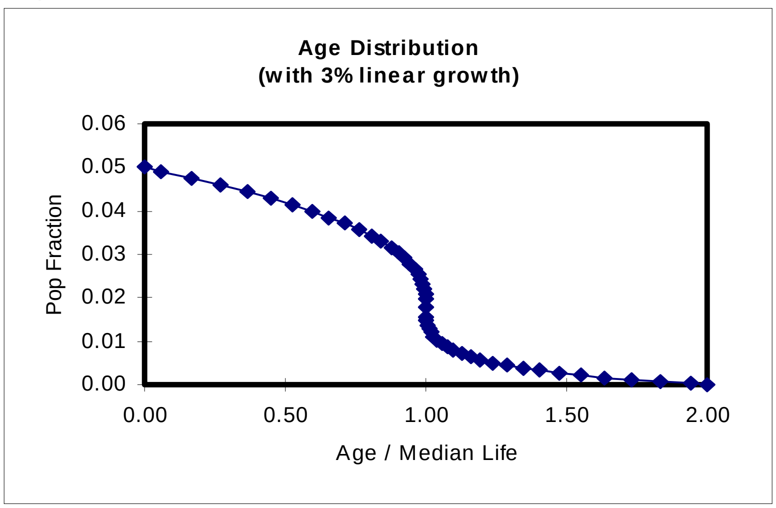


Figure 3 Survival Fraction (with growth)

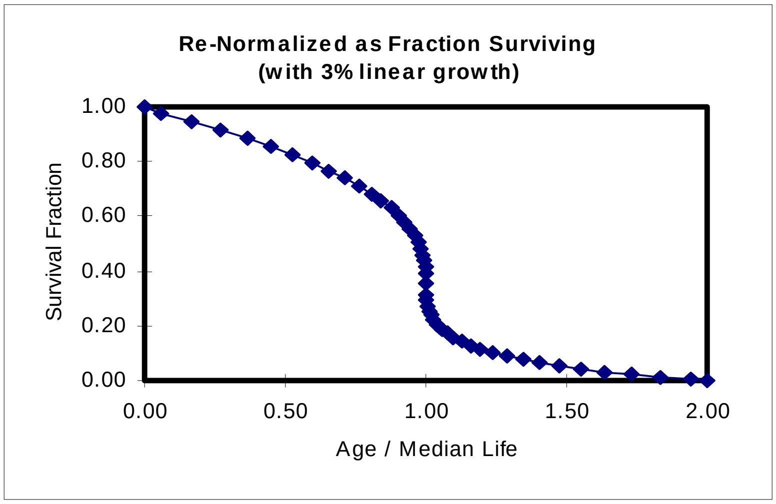
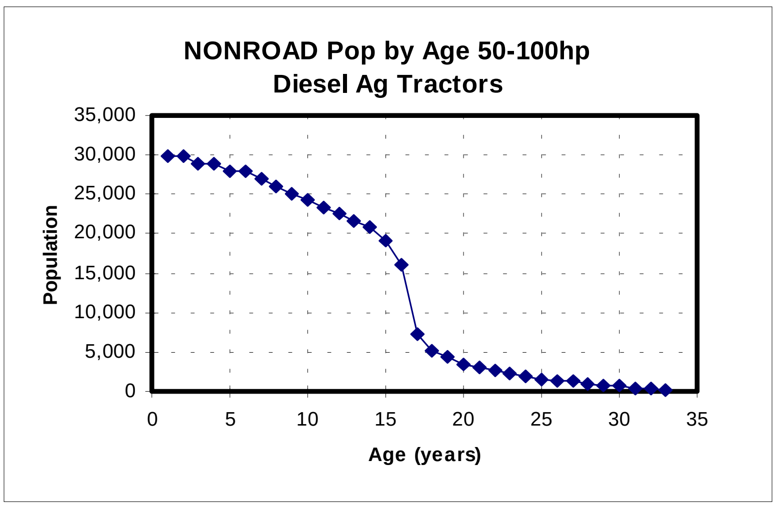


Figure 4 Age Distribution Example (with growth)



Limitations of this Methodology:

As in previous versions of NONROAD, any type of equipment that is relatively new to the world, or has had substantial increases in sales in recent years, will not have a real world age distribution based simply on median life and scrappage parameters, which is how it is modeled. I.e., the model will show more older units than are actually out there, since they haven't been on the market long enough to fill out their full scrappage curve, or because the population is dominated by recent year sales.

Inputs

The calculation of age distributions requires the following data to be supplied to the NONROAD model:

- Equipment Population and Median Life at full load
- Growth Indicators
- Scrappage Curve
- Activity and Load Factor

These data are input to the model using data files. The format of the data files is described below, examples of data are given, and the location of the data is specified. For more information on equipment activity, load factors, median life, and populations see the EPA technical reports on these subjects, NR-005b [3] and NR-006b [4].

Equipment Populations and Median Life at Full Load

Equipment population data for each state and nationwide are provided in the directory "data/pop." If estimates are provided for more than one year, the NONROAD model will use the closest year which comes before the target year. Since median life depends on equipment type and horsepower range, the median life at full load parameter is also included in the population data file.

The format of the data in the /POPULATION/ packet is as follows:

Columns	Description
1 - 5	FIPS code
7 - 11	subregion code (used for subcounty estimates)
13 - 16	year of population estimates
18 - 27	SCC code (no globals accepted)
29 - 68	equipment description (ignored)
70 - 74	minimum HP range
76 - 80	maximum HP range (ranges must match those internal to model)
82 - 86	average HP in range (if blank model uses midpoint)
88 - 92	median expected life (in hours of use at full load)
93 - 102	flag for scrappage distribution curve (DEFAULT = standard curve)
106 - 122	population estimate

An example of data from a /POPULATION/ packet is given below (note that lines are wrapped to fit the page).

```
00000       1996  2265004010  4-Str Lawn mowers (res) 1     3     2.55
      47.9  DEFAULT     636892
00000       1996  2265004010  4-Str Lawn mowers (res) 3     6     4.1
      47.9  DEFAULT     31652672
00000       1996  2265004010  4-Str Lawn mowers (res) 6     11    6.24
      400   DEFAULT     10436
```

Growth Indicators

The default data are based on national growth estimates for the various source category groups. Data are located in the “data/growth” directory in a single file that contains both data packets:

/INDICATORS/	Cross reference between SCC code and growth indicator code.
/GROWTH/	Numerical values for different growth indicator codes.

An indicator code is an alphanumeric code used to identify which set of growth index inputs to use for a given type of equipment. The growth indicator codes used in the /INDICATORS/ packet must match one of the codes provided in the /GROWTH/ packet. Cross referencing between the /INDICATORS/ and /GROWTH/ packets is based on FIPS code, SCC code, horsepower (HP) range, and technology type. The model uses the best match to the codes provided, falling back on global values if a unique match is not found.

The format of the data in the /INDICATORS/ packet is as follows:

Columns	Description	
1- 5	FIPS code	(00000 = applies to entire nation) (ss000 = applies to all of state ss)
7-10	Indicator code	(arbitrary alphanumeric code)
12-21	SCC code	(2260004000 = applies to all 2-stroke lawn and garden) (2600000000 = applies to all 2-stroke)
23-27	Beginning of HP range	
28-32	Ending of HP range	
34-43	Technology type (ALL = applies to all tech types)	

An example data record from the /INDICATORS/ packet is given below.

```
00000 052  2265004000     0 9999 ALL        4-Stroke Lawn & Garden Equip.
```

The format of the data in the /GROWTH/ packet is as follows:

1- 5	FIPS code	(00000 = applies to entire nation) (ss000 = applies to all of state ss)

6-10	Subregion code (blank = applies to all subregions)
11-15	Year of estimate (4-digit year)
17-20	Indicator code (arbitrary alphanumeric code)
26-45	Indicator value

Example of a few data records from the /GROWTH/ packet:

```
00000      1996  052                       1000
00000      1998  052                       1045
00000      2000  052                       1090
00000      2005  052                       1210
00000      2010  052                       1329
00000      2015  052                       1449
00000      2025  052                       1688
00000      2045  052                       2166
```

Scrappage Curve

A single default scrappage curve is used by the NONROAD model. The scrappage curve is read in from the same data file as the growth data in the “data/growth” directory.

Table 1. Default Scrappage Curve

Age/Median Life*	Percent Scrapped	Age/Median Life	Percent Scrapped
0.0000	0	continued...	
0.0588	1	1.0010	55
0.1694	3	1.0027	57
0.2710	5	1.0058	59
0.3639	7	1.0106	61
0.4486	9	1.0176	63
0.5254	11	1.0270	65
0.5948	13	1.0393	67
0.6570	15	1.0549	69
0.7125	17	1.0741	71
0.7617	19	1.0973	73
0.8049	21	1.1250	75
0.8425	23	1.1575	77
0.8750	25	1.1951	79
0.9027	27	1.2383	81
0.9259	29	1.2875	83
0.9451	31	1.3430	85
0.9607	33	1.4052	87
0.9730	35	1.4746	89
0.9824	37	1.5514	91
0.9894	39	1.6361	93
0.9942	41	1.7290	95
0.9973	43	1.8306	97
0.9990	45	1.9412	99
1.0000	50	2.0000	100

* Age in hours/load factor;
  Median Life in hours at full load.

Activity and Load Factor

The /ACTIVITY/ packet defines how often a piece of equipment is used in a year. The file also contains other information about the equipment, most notably the average load factor.

The format of the /ACTIVITY/ packet is as follows:

Columns	Description
1-10	SCC code
12-51	Equipment description (not used)
52-56	Region code
57-66	Technology type
67-71	Minimum HP
72-76	Maximum HP

77-81	Load factor
82-86	(not used)
87-96	Activity level units
97-106	Activity level
107-116	Identifier for age adjustment curve (DEFAULT = no adjustment)

An example data record from the /ACTIVITY/ packet is (note that lines are wrapped to fit on page):

```
2265004010 4-Stroke Lawn mowers (Residential)                ALL
  0 9999 0.33        Hrs/Yr         25  DEFAULT
```

Glossary of Terms

Term	Definition
Accumulated scrappage	The total amount of scrappage that has occurred for equipment of a given model year since its introduction into service
Activity level	The number of hours per year that the equipment in question operates
Age distribution	The function that describes the proportion of in-service equipment by age; consists of the full set of model year fractions for a given year
Annual Growth Rate	The linear rate, relative to 1996, at which the equipment population is projected to grow each year in order to reach a specified level
Annualized scrappage curve	The result of scaling the scrappage curve by the average lifetime of the equipment in question
Average lifetime	The age in years at which half of the equipment will have been scrapped (removed from service)
Base year	The year for which the population of a given type of equipment is specified in the population input file
In-service fraction	The fraction of the engines originally sold in a given year which are still in service; the inverse of accumulated scrappage
Load factor	The average power level at which the engine operates divided by the maximum available power
Median life at full load	The number of hours that a given type of equipment is expected to survive, if it were operated at full load

Glossary of Terms, cont'd

Term	Definition
Model year	Refers to the year in which equipment was produced. Equipment of the same model year was produced in the same year. To clarify the relationship between age and model year, consider the following example: 1990-model year equipment is (on average) six years old in 1996 and ten years old in 2000.
Model year fraction	The fraction of the total equipment population represented by a given model year at a given point in time
Population growth rate	The rate at which the equipment population increases each year
Scrappage curve	A graphical representation of the scrappage function
Scrappage function	The relationship between equipment age (expressed in terms of the fraction of average lifetime) and the proportion of equipment that has been removed from service, i.e., scrapped
Scrappage rate	The percentage of equipment of a given age removed from service in a given year
Target year	The calendar year for which the NONROAD model's user wishes to estimate emissions and other quantities
Total equipment population	The total number of pieces of equipment in service at a given point in time; the sum of the populations of each model year still in service

References

[1] "Calculation of Age Distributions in the Nonroad Model: Growth and Scrappage," NR-007, U.S. Environmental Protection Agency, Office of Transportation and Air Quality, February 18, 1998.

[2] "Nonroad Engine Growth Estimates," NR-008b, U.S. Environmental Protection Agency, Office of Transportation and Air Quality, May 2002.

[3] "Median Life, Annual Activity, and Load Factor Values for Nonroad Engine Emissions Modeling," NR-005b, U.S. Environmental Protection Agency, Office of Transportation and Air Quality, May 2002.

[4] "Nonroad Engine Population Estimates," NR-006b, U.S. Environmental Protection Agency, Office of Transportation and Air Quality, May 2002.

Appendix: Example of Scrappage Curve Modification for Growth (3% linear)

Frac Med Life Used	Percent Scrapped	Fraction Surviving	Age Years	Orig. Sales Ratio	Surviving Pop Ratio	Age Distrib.	Normalized as %"Scrapped"
0.0000	0	1	1	2.4400	2.4400	0.05026	0.00
0.0588	1	0.99	2	2.4100	2.3859	0.04915	2.22
0.1694	3	0.97	3	2.3800	2.3086	0.04756	5.39
0.2710	5	0.95	4	2.3500	2.2325	0.04599	8.50
0.3639	7	0.93	5	2.3200	2.1576	0.04444	11.57
0.4486	9	0.91	6	2.2900	2.0839	0.04293	14.59
0.5254	11	0.89	7	2.2600	2.0114	0.04143	17.57
0.5948	13	0.87	8	2.2300	1.9401	0.03996	20.49
0.6570	15	0.85	9	2.2000	1.8700	0.03852	23.36
0.7125	17	0.83	10	2.1700	1.8011	0.03710	26.18
0.7617	19	0.81	11	2.1400	1.7334	0.03571	28.96
0.8049	21	0.79	12	2.1100	1.6669	0.03434	31.68
0.8425	23	0.77	13	2.0800	1.6016	0.03299	34.36
0.8750	25	0.75	14	2.0500	1.5375	0.03167	36.99
0.9027	27	0.73	15	2.0200	1.4746	0.03038	39.57
0.9259	29	0.71	16	1.9900	1.4129	0.02910	42.09
0.9451	31	0.69	17	1.9600	1.3524	0.02786	44.57
0.9607	33	0.67	18	1.9300	1.2931	0.02664	47.00
0.9730	35	0.65	19	1.9000	1.2350	0.02544	49.39
0.9824	37	0.63	20	1.8700	1.1781	0.02427	51.72
0.9894	39	0.61	21	1.8400	1.1224	0.02312	54.00
0.9942	41	0.59	22	1.8100	1.0679	0.02200	56.23
0.9973	43	0.57	23	1.7800	1.0146	0.02090	58.42
0.9990	45	0.55	24	1.7500	0.9625	0.01983	60.55
1.0000	50	0.5	25	1.7200	0.8600	0.01772	64.75
1.0010	55	0.45	26	1.6900	0.7605	0.01567	68.83
1.0027	57	0.43	27	1.6600	0.7138	0.01470	70.75
1.0058	59	0.41	28	1.6300	0.6683	0.01377	72.61
1.0106	61	0.39	29	1.6000	0.6240	0.01285	74.43
1.0176	63	0.37	30	1.5700	0.5809	0.01197	76.19
1.0270	65	0.35	31	1.5400	0.5390	0.01110	77.91
1.0393	67	0.33	32	1.5100	0.4983	0.01026	79.58
1.0549	69	0.31	33	1.4800	0.4588	0.00945	81.20
1.0741	71	0.29	34	1.4500	0.4205	0.00866	82.77
1.0973	73	0.27	35	1.4200	0.3834	0.00790	84.29
1.1250	75	0.25	36	1.3900	0.3475	0.00716	85.76
1.1575	77	0.23	37	1.3600	0.3128	0.00644	87.18
1.1951	79	0.21	38	1.3300	0.2793	0.00575	88.55
1.2383	81	0.19	39	1.3000	0.2470	0.00509	89.88
1.2875	83	0.17	40	1.2700	0.2159	0.00445	91.15
1.3430	85	0.15	41	1.2400	0.1860	0.00383	92.38
1.4052	87	0.13	42	1.2100	0.1573	0.00324	93.55
1.4746	89	0.11	43	1.1800	0.1298	0.00267	94.68
1.5514	91	0.09	44	1.1500	0.1035	0.00213	95.76
1.6361	93	0.07	45	1.1200	0.0784	0.00161	96.79
1.7290	95	0.05	46	1.0900	0.0545	0.00112	97.77
1.8306	97	0.03	47	1.0600	0.0318	0.00066	98.70
1.9412	99	0.01	48	1.0300	0.0103	0.00021	99.58
2.0000	100	0	49	1.0000	0.0000	0.00000	100.00
Sum:					48.5456	1.00000	