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Update Heavy-Duty Engine Emission Conversion Factors for MOBILE6: Analysis of Fuel Economy, Non-Engine Fuel Economy Improvements, and Fuel Densities

UPDATE HEAVY-DUTY ENGINE EMISSION CONVERSION FACTORS FOR MOBILE6

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05 May 1998

PREPARED FOR

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I. INTRODUCTION

The USEPA highway emission factor model, MOBILE5a, calculates average in-use emission factors for hydrocarbons (HC), carbon monoxide (CO), and oxides of nitrogen (NO_x) for eight categories of vehicles including heavy-duty gasoline (HDGV) and heavy-duty diesel (HDDV) vehicles (all vehicles with a gross vehicle weight of 8501 pounds or more). These emission factors are expressed in units of grams per mile (g/mi) and are used in combination with data on vehicle miles traveled (VMT) to estimate highway vehicle contributions to mobile source emission inventories. However, since emission standards for both gasoline and diesel heavy-duty vehicles are expressed in terms of grams per brake-horsepower-hour (g/bhp-hr), conversion factors in terms of brake-horsepower-hour per mile (bhp-hr/mi) must be used to convert the emission certification data from engine testing to in-use grams per mile. These conversion factors have been calculated several times over the last 15 years with the last update completed by USEPA in 1988 for all heavy-duty vehicles [1][1].

The conversion factors used in MOBILE5a were calculated from the following expression:

$$\text{Conversion Factor (bhp-hr/mi)} = \frac{\text{Fuel Density (lb/gal)}}{\text{BSFC (lb/bhp-hr)} \times \text{Fuel Economy (mi/gal)}}$$

where BSFC is brake specific fuel consumption.

It is the intent of Work Assignments 0-03 and 1-02 to update these conversion factors for all weight classes listed in Table 1. Since the last update calculated conversion factors through the 1986 model year, it is the purpose of this work to calculate conversion factors for model years 1987 through 1996 and project conversion factors for model years 1997 through 2050.

This report discusses the analysis of fuel economy for model years 1987 through 1996 and fuel density for gasoline and diesel. Furthermore, it examines the use of non-engine fuel economy improvement devices for forecasting conversion factors in the future.

This report first discusses the data sets used in analyzing fuel economy and fuel density, then describes analysis methodology and results. Further details of the analyses can be found in the appendices. A second report, "Update Heavy-Duty Engine Emission Conversion Factors for MOBILE6: Analysis of BSFCs and Calculation of Heavy-Duty Engine Emission Conversion Factors," discusses the analysis of brake specific fuel consumption data and provides the calculation of updated engine emission conversion factors.

II. DATA SETS

A. Truck Fuel Economy and Non-Engine Fuel Economy Improvements

Average truck fuel economy and non-engine fuel economy improvements were calculated using the 1992 Truck Inventory and Use Survey (TIUS) Microdata File [2]. The 1992 TIUS survey was

[1] Numbers in brackets refer to references listed in Section V.

conducted during the 1992-1993 time frame by the U.S. Bureau of the Census. The database, which was supplied on CD-ROM, compiles a statistically significant sample of on-road light-duty and heavy-duty trucks. The data includes the attributes of age, gross vehicle weight, fuel type, fuel economy, average operating weight, travel type fraction, and mileage accumulation during 1992 for each truck surveyed. The Census Bureau has also assigned an expansion factor on each record to extrapolate the information in their database to represent the entire US truck population. The data also includes information on use of non-engine fuel economy improvements such as aerodynamic devices, drive train optimization, radial tires, governors and variable fan drives. This data set was used for both gasoline and diesel trucks.

Table 1. Vehicle weight classes

Designation	Description	Gross Vehicle Weight (lb)
HDGV (class 2B)	Light heavy-duty gasoline vehicles	8501-10,000
HDGV (class 3)	Light heavy-duty gasoline vehicles	10,001-14,000
HDGV (class 4)	Heavy heavy-duty gasoline vehicles	14,001-16,000
HDGV (class 5)	Heavy heavy-duty gasoline vehicles	16,001-19,500
HDGV (class 6)	Heavy heavy-duty gasoline vehicles	19,501-26,000
HDGV (class 7)	Heavy heavy-duty gasoline vehicles	26,001-33,000
HDGV (class 8A)	Heavy heavy-duty gasoline vehicles	33,001-60,000
HDGV (class 8B)	Heavy heavy-duty gasoline vehicles	>60,000
HDGTB	Gasoline transit buses	all
HDGSB	Gasoline school buses	all
HDGCB	Gasoline intercity buses	all
HDDV (class 2B)	Light heavy-duty diesel trucks	8501-10,000
HDDV (class 3)	Light heavy-duty diesel trucks	10,001-14,000
HDDV (class 4)	Light heavy-duty diesel trucks	14,001-16,000
HDDV (class 5)	Light heavy-duty diesel trucks	16,001-19,500
HDDV (class 6)	Medium heavy-duty diesel trucks	19,501-26,000
HDDV (class 7)	Medium heavy-duty diesel trucks	26,001-33,000
HDDV (class 8A)	Heavy heavy-duty diesel trucks	33,001-60,000
HDDV (class 8B)	Heavy heavy-duty diesel trucks	>60,000
HDDTB	Diesel transit buses	all
HDDSB	Diesel school buses	all
HDDCB	Diesel intercity buses	all

B. Bus Fuel Economy

Data on in-use bus fuel economy was not as readily available as that for trucks. Counts of transit buses by model year and engine type was obtained from the American Public Transit Association (APTA) *1995 Transit Passenger Vehicle Fleet Inventory* [3]. Fuel economy for the various common engine types was taken from a National Renewable Energy Laboratory (NREL) study of transit buses [4]. The APTA *1996 Transit Fact Book* [5] was used to confirm calculations against average fuel economy figures.

For school buses, limited data from the *National Transportation Statistics 1997* [6] together with data from a school bus vehicle demonstration program [7] and school bus type counts by model year from *School Bus Fleet Magazine* [8] were used to characterize gasoline and diesel school bus fuel economy. Diesel intercity bus fuel economy was estimated from comparisons of similar buses with DDC 6V-92TA engines (the most common engine prior to 1994) during a central business district (CBD) cycle and an commuter cycle (COM) [9].

Gasoline fuel economies for transit and intercity buses by model year could not be located. Since these represent a small portion of the inventory, previous work by Machiele [1] was used to estimate gasoline transit and intercity bus fuel economies. Further discussion of these assumptions and calculations are described in Section III(B).

C. Fuel Density

Fuel densities were determined from National Institute for Petroleum and Energy Research (NIPER) Petroleum Product Surveys (PPS) for years 1987 through 1996 [10-26]. These documents list diesel and summer and winter gasoline properties.

III. METHODOLOGY

Methodologies to determine fuel economy, non-engine fuel economy improvement penetration and fuel density data are presented below.

A. TIUS Methodology

To provide the best analysis of the TIUS data for the purposes needed by this work assignment, ARCADIS Geraghty & Miller manipulated the TIUS data on a record-by-record basis. Pertinent data from the TIUS data file TI92MDF.DAT was converted into a comma-delimited file using a C program (TIHDCF.C), which is listed in the appendices. The comma-delimited file was then appended to a dBASE file (TIUSHDCF.DBF) with the structure presented in Table 2. Two additional fields were added to TIUSHDCF.DBF to further help in the manipulation of the data for this work assignment. They are listed in Table 3.

The TIUS data set contains 247,282 records. These records were separated into the various truck weight classes listed in Table 1 using the TIUS gross vehicle weight class (TIUGVW), the fuel type (ENGTYP), and the average operating weight (AVGWT). The parameters TIUGVW and AVGWT were used to determine weight class since these parameters are cross checked by the Census Bureau and gave consistent results in terms of fuel economy versus weight class. Since TIUGVW does not differentiate between classes 2A (6,001 - 8,500 lbs) and 2B (8,501 -10,000 lbs), AVGWT was used to determine which trucks were class 2B. Records which did not fall into one of the classes defined in Table 1, were incomplete, or used a fuel other than gasoline or diesel, were eliminated. In addition, since the last model year of data included model years 1982 and older, these data were also eliminated as they could not be assigned to a specific model year. This resulted in 59,046 records for the analysis.

Results defined by 2 or less records were also deleted. The data were then used to characterize average fuel economy, travel fractions, average operating weight, vehicle miles traveled (VMT) and penetration of non-engine fuel economy improvements for the classes of vehicles listed in Table 1.

Table 2. TIUSHDCF.DBF data structure

Field Name	Description
EXPANF	Expansion factor
MDLYR	Model year
AVGWT	Average operating weight
ENGTYP	Fuel type
PKCID	Engine size code
AERODN	Aerodynamic device?
AXLRAT	Optimized axle ratio?
ECOENG	Fuel economy engine?
RADIAL	Radial tires?
GOVNOR	Road speed governor?
VARFAN	Variable fan drives?
OTHFUEL	Other fuel conservation features?
ANNMIL	Annual Mileage during 1992
MPG	Fuel Economy
PLOCAL	% of mileage for trips < 50 miles from home
PSHORT	% of mileage for trips 50-100 miles from home
PSMED	% of mileage for trips 100-200 miles from home
PLMED	% of mileage for trips 200-500 miles from home
PLONG	% of mileage for trips > 500 miles from home
TIUGVW	TIUS gross vehicle weight class
PKGVW	Polk gross vehicle weight class
PKRWGT	Polk registered weight

Table 3. Additional fields in TIUSHDCF.DBF

Field Name	Description
WGTCLASS	Vehicle class description
TRIP CODE	Trip type description

Trip types were broken into four trip categories as shown in Table 4 for further analysis. It was believed that fuel economies would be different for trucks that operated locally to those that operated in long-haul applications. Vehicle characteristics versus trip type were determined from records in which over 75 percent of the VMT represented that trip type. All values were averaged by vehicle miles traveled (registrations times annual average mileage). The program to manipulate the database, HDCF.PRG, is listed in the appendices.

Table 4. Trip type descriptions

Trip Type	Description
Local	Trips less than 50 miles from home base
Short	Trips between 50 and 100 miles from home base
Medium	Trips between 100 and 200 miles from home base
Long	Trips over 200 miles from home base

A regression analysis was performed for fuel economies by model year for each weight class and a power curve fit ($y = ax^b$) was generated to extrapolate values beyond 1992. Curve fits for each weight class are shown in Table 5. TIUS provided the most complete set of in-use fuel economy data for trucks, but since it only described trucks for 1992 model year and older, the fuel economy curves needed to be extrapolated to provide data for model years 1993 through 1996. In all cases the equations resulted in about a 1% improvement in fuel economy per year which seemed reasonable given current truck fuel economy trends. TIUS provided no data for Class 8B gasoline trucks and therefore no fuel economies were calculated for that class. No extrapolation beyond 1996 was done for fuel economy since BSFCs beyond 1996 were not available. Future projections of conversion factors were made based upon conversion factors calculated between 1987 and 1996, similar to the methodology applied by Machiele [1].

Table 5. Curve fits of fuel economy
(y is fuel economy in mpg and x is [model year - 1900])

Weight Class	Gasoline	Diesel
2B	$y = 0.1253x^{0.9624}$	$y = 0.1072x^{1.0506}$
3	$y = 0.1157x^{0.9632}$	$y = 0.0989x^{1.045}$
4	$y = 0.0409x^{1.1902}$	$y = 0.502x^{0.6598}$
5	$y = 0.4416x^{0.6348}$	$y = 0.2474x^{0.8078}$
6	$y = 0.0338x^{1.2015}$	$y = 0.5336x^{0.6117}$
7	$y = 0.1277x^{0.8909}$	$y = 4.0206x^{0.1374}$
8A	$y = 0.0647x^{1.0285}$	$y = 0.15485x^{0.8194}$
8B	--	$y = 0.0119x^{1.3742}$

Non-engine fuel economy improvement penetration versus model year for model years 1983 through 1992 were curve fit using a logarithmic curve ($y = a + b*\ln(x)$). Usage of non-engine fuel economy improvements for the 1996 model year were then calculated using the curve fits and compared against MOBILE4 estimates [1]. Discussion of these results can be found in Section IV. Raw averaged TIUS data for each weight class and fuel can be found in the appendices (Tables A-1 through A-15). Blank entries indicate no data.

B. Bus Fuel Economy Methodology

Diesel transit bus fuel economy is highly dependent on the type of engine used. Prior to 1993, 68 to 87% of the diesel bus inventory used the DDC 6V-92TA two-stroke engine. The Cummins L-10 four-stroke engine was the second most used engine in transit buses during that time period. The Cummins L-10 has approximately 14% better fuel economy than the DDC 6V-92TA [4]. In 1992, DDC introduced the Series 50 four stroke engine for the bus market with approximately 16% better fuel economy than the 6V-92TA [27]. Due to more stringent emission regulations, the 6V-92 is being phased out and will not be built after 1998 for the on-road market. The penetration of the four stroke engines into the bus market each model year is a larger driver of average fleet fuel economy than the minor changes that occur from year to year in a given engine line. Thus to calculate fuel economy for this work assignment, bus engine counts for model years 1987 through 1995 were taken from the APTA *1995 Transit Passenger Vehicle Fleet Inventory* [2]. These are listed in Table 6. As transit buses are defined in the Code of Federal Regulations (Title 40 §86.093-2) as having a load capacity of 15 passengers or more, buses that held fewer than 15 passengers were not counted. In addition, trolleys and streetcars also were not counted. The numbers in Table 6 represent active buses for model years 1987 through 1994 and purchases for 1995.

Table 6. Diesel transit bus inventory by engine type
(U.S. in-service population)

Model	DDC			Cummins	Other
Year	Series 50	6V-92TA	8V-92TA	L-10	Engines
1987		2189	33	355	238
1988		1826	5	683	142
1989		2983	102	239	96
1990		2910	34	1087	204
1991		1979	1	189	180
1992		1394	50	365	78
1993	257	1473	12	361	148
1994	1604	243	11	603	28
1995	1370	200		333	21

Average fuel economies for the DDC 6V-92TA and the Cummins L-10 were derived from a transit bus study done by NREL [4] and are listed in Tables 7 and 8 respectively. Average fuel economies were determined by weighting each transit district average diesel fuel economy by the fleet mileage. This resulted in a 14% increase in fuel economy for the four stroke L-10 over the two stroke 6V-92TA.

Comparisons of certification BSFCs for the 6V-92 and the Series 50 showed a 16% improvement in fuel economy for the newer four stroke Series 50. The DDC 8V-92TA was assumed to have the same fuel economy as the DDC 6V-92TA since the DDC 8V-92TA has slightly better BSFC but is usually used in heavier buses. The other engines in Table 6 were also mostly four stroke engines (mostly Caterpillar 3306). Using this information, fuel economies for two-stroke buses were estimated to be 3.4 mpg (DDC 6V-92 and 8V-92) and four-stroke buses were estimated to be 3.9 mpg (DDC Series 50, Cummins L-10 and others). Fuel economy by model year for diesel transit buses was then weighted by the vehicle counts listed in Table 6.

Table 7. Determination of average diesel transit bus fuel economies for the DDC 6V-92TA (Taken from Reference 4)

Transit District	No. of Buses	Fleet Miles (miles)	Average Fuel Economy (mpg)
Houston TX	5	282,881	3.63
Miami FL	5	380,453	3.32
Peoria IL	3	225,377	3.51
Minneapolis/St. Paul MN	5	266,338	3.14
VMT Weighted Average			3.39

Table 8. Determination of average diesel transit bus fuel economies for the Cummins L-10 (Taken from Reference 4)

Transit District	No. of Buses	Fleet Miles (miles)	Average Fuel Economy (mpg)
Portland OR	5	203,007	4.30
Miami FL	5	330,342	3.61
VMT Weighted Average			3.87

Intercity bus fuel economy was estimated from transit bus fuel economy by applying the percent increase in fuel economy between a transit bus operating on the central business district (CBD) driving cycle and the commuter (COM) cycle. Intercity buses are similar to transit buses, but stop less and usually travel at higher speeds. Since intercity buses travel freeways and arterials between cities, the COM driving cycle is a good representation of intercity bus use. The CBD is used to represent in-city driving by transit buses. Battelle Columbus Laboratories tested six transit buses with 6V-92TA engines on both the CBD and COM cycles [9]. Averaged results from that study is shown in Table 9.

Diesel buses driven on the COM cycle had a 35.2% increase in fuel economy over that for the same bus driven on the CBD cycle. Thus fuel economies for diesel transit buses by model year were then multiplied by 1.352 to determine intercity bus fuel economies.

Gasoline school bus fuel economies were calculated from fuel usage and vehicle-mile statistics for school buses from the *National Transportation Statistics 1997* [6]. Gasoline school buses werel assumed to be mostly Type A&B[2]. To calculate diesel school bus fuel economy for Type A&B, the ratio of diesel to gasoline fuel economies for school buses was determined from a 1988 report on conversion factors [1] and applied to fuel economies calculated for gasoline Type A&B school buses. This resulted in an estimate of 8.2 mpg for Type A&B diesel school buses. Fuel economies for Type C and D buses were taken from a California Energy Commission school bus demonstration program [7]. Average fuel economy for Type C & D buses from that study was approximately 6.0 mpg. Using these estimates together with the school bus populations by vehicle type from *School Bus Fleet* [8] (shown in Table 10), diesel school bus fuel economy was calculated.

Table 9. Fuel economy difference between CBD and COM driving cycles
(Taken from Reference 9)

Driving Cycle	**Miles between Stops**	**Average Speed** (mph)	**Top Speed** (mph)	**Fuel Economy** (mpg)
CBD	0.142	12.9	20	3.69
COM	4.000	46.5	55	4.99
Ratio of COM to CBD fuel economy				1.352

Table 10. Diesel school bus inventory by model year and type
(Taken from Reference 8)

Model Year	**School Bus Type**			
	A&B	**C**	**D**	**Total**
90	2225	23670	6286	32181
91	3756	21370	6864	31990
92	3820	16444	5444	25708
93	3535	18928	6734	29197
94	3215	21005	7321	31541
95	2216	20861	9671	32748
96	2225	22016	9270	33511

[2] Types A & B are generally smaller school buses with the engine in the front. Types C and D are generally larger school buses, Type C has a front engine and Type D has an engine in the rear or midship.

The gasoline transit bus inventory amounted to approximately 0.5% of the diesel transit bus inventory [3]. To calculate gasoline transit bus fuel economies, the ratio of diesel to gasoline fuel economies for transit buses was determined from a 1988 report on conversion factors [1]. That report indicated that gasoline transit buses fuel economies were approximately 90.8% of diesel transit bus fuel economies. This factor was applied to the previously calculated diesel transit bus fuel economies to determine gasoline transit bus fuel economies. A similar procedure was used for gasoline intercity buses, but in this case, the ratio was determined between gasoline transit and intercity buses. It was determined from Reference 9 that gasoline intercity buses had 16.7% better fuel economy than gasoline transit buses. Thus gasoline transit bus fuel economy by model year was multiplied by 1.167 to determine gasoline intercity bus fuel economies.

C. Fuel Density Methodology

1. Gasoline

Gasoline American Petroleum Institute (API) gravity was extracted from NIPER publications on summer and winter motor gasoline properties. It was assumed that all heavy-duty gasoline trucks use regular unleaded gasoline. Low altitude values were used for all years. Summer and winter values were averaged (added together and divided by two) for each year in question. Fuel densities in pounds per gallon were then calculated from API gravity using the following formula [28]:

$$\text{Fuel Density (lbs/gal)} = \frac{141.5 \times 8.328}{(131.5 + \text{API})}$$

2. Diesel

Diesel API gravity was extracted from NIPER publications on diesel properties. It was assumed that all heavy-duty diesel trucks and buses use #2 diesel fuel. Nationwide average values were used to calculate fuel densities for each year. Fuel densities in pounds per gallon were then calculated from API gravity using the above formula.

IV. RESULTS

A. Truck Fuel Economy

Average heavy-duty gasoline truck operation by weight class during 1992 (1992 TIUS data) is presented in Table 11. Both fuel economy and average operating weight are VMT weighted averages. In all weight classes except 4, over 60% of the VMT occurred in trips within 50 miles of the home base of the vehicle (Local). All weight classes except 4 had over 80% of the VMT within 100 miles from the home base of the vehicle (Local + Short). Class 4 vehicles had only 66% of the VMT within 100 miles from the home base.

Gasoline truck fuel economy was calculated for 1987 through 1996 model year trucks using the curve fits listed in Table 5 (derived from TIUS data). The results are shown in Table 12.

Table 13 shows average heavy-duty diesel truck operation by weight class during 1992 (1992 TIUS data). Both fuel economy and average operating weight are VMT weighted averages. As with gasoline vehicles, local operation (Local) was compared with long-haul (Long) operation to determine trends in fuel economy. Data in Tables 11 and 13 indicate that diesel trucks tended to operate over a greater radius from home base than gasoline trucks. Weight classes 2B through 7 drove over 40% of their VMT on trips within 50 miles of the home base of the vehicle (Local). These trips accounted for only 23% and 7% of their VMT for weight classes 8A and 8B, respectively. Class 8A had almost 50% of VMT in trips over 200 miles from the home base (Long), while class 8B drove over 70% of the VMT in trips over 200 miles from the home base. The TIUS data also show that for class 8 trucks, fuel economy for local trips was approximately equal to fuel economy for long-haul trips. It is expected that these results would be different for trucks with newer, electronically-controlled engines.

Table 11. Heavy-duty gasoline vehicle averages in 1992 (taken from 1992 TIUS[2])

Weight Class	VMT (Mil Miles)	Travel Fraction (%)				FE[a] (mpg)	Wgt[b] (lbs)
		Local	Short	Med	Long		
2B	3283.02	64.3	25.7	8.8	1.2	9.2	9490
3	4194.68	65.9	16.2	7.4	10.4	9.0	11997
4	1224.18	46.4	19.8	7.4	26.5	8.2	15274
5	765.40	72.4	19.3	5.9	2.5	7.4	17877
6	1301.57	68.9	17.1	2.3	11.7	7.3	22289
7	443.19	76.6	10.6	10.2	2.6	6.7	29068
8A	165.04	73.0	19.3	5.3	2.4	6.6	39838

[a] Average weight class fuel economy in miles per gallon
[b] Average weight class operating weight in pounds

Table 12. Projected gasoline heavy-duty vehicle fuel economies (mpg)

Model Year	Weight Class						
	2B	3	4	5	6	7	8A
87	9.22	8.54	8.32	7.52	7.23	6.83	6.39
88	9.32	8.63	8.43	7.58	7.33	6.89	6.47
89	9.42	8.73	8.55	7.63	7.43	6.96	6.54
90	9.52	8.82	8.66	7.68	7.53	7.03	6.62
91	9.62	8.92	8.78	7.74	7.63	7.10	6.70
92	9.73	9.01	8.89	7.79	7.73	7.17	6.77
93	9.83	9.11	9.01	7.85	7.84	7.24	6.85
94	9.93	9.20	9.12	7.90	7.94	7.31	6.92
95	10.03	9.30	9.24	7.95	8.04	7.38	7.00
96	10.13	9.39	9.35	8.01	8.14	7.45	7.07

Table 14 shows calculated fuel economy for model year 1987 through 1996 diesel trucks, derived from the curve fits listed in Table 5.

Table 13. Heavy-duty diesel vehicle averages in 1992 (taken from 1992 TIUS [2])

Wgt	VMT	Travel Fractions (%)				Fuel Economy[a] (mpg)			Average Weight[b] (lbs)		
Class	Mil Miles	Local	Short	Med	Long	Ave	Local	Long	Ave	Local	Long
2B	1857.59	55.0	31.4	9.0	4.5	11.9	12.0		9591	9544	
3	3751.85	49.2	30.2	8.5	12.1	11.2	12.1		12219	12262	
4	1479.63	47.2	37.2	8.1	7.5	9.7	9.5		15123	15185	
5	1857.42	55.9	18.8	9.3	15.9	9.4	9.4	9.6	17814	17812	17916
6	5492.44	47.9	28.8	12.8	10.5	8.2	8.0	8.5	22935	22829	23366
7	4768.90	44.0	22.6	10.2	23.2	7.4	7.7	6.6	29906	30074	30350
8A	25088.28	22.7	10.7	9.9	56.6	6.0	6.0	6.0	48881	47622	49900
8B	65513.19	7.3	8.8	9.4	74.4	5.7	5.6	5.7	75784	76575	75063

[a] Average weight class fuel economy in miles per gallon
[b] Average weight class operating weight in pounds

Table 14. Projected diesel heavy-duty vehicle fuel economies (mpg)

Model	Weight Class							
Year	2B	3	4	5	6	7	8A	8B
87	11.69	10.52	9.56	9.12	8.20	7.43	5.96	5.51
88	11.83	10.65	9.63	9.21	8.25	7.44	6.03	5.59
89	11.97	10.77	9.70	9.29	8.31	7.45	6.10	5.68
90	12.11	10.90	9.77	9.38	8.37	7.46	6.17	5.77
91	12.26	11.03	9.85	9.46	8.42	7.47	6.24	5.86
92	12.40	11.15	9.92	9.54	8.48	7.48	6.31	5.95
93	12.54	11.28	9.99	9.63	8.54	7.49	6.38	6.03
94	12.68	11.41	10.06	9.71	8.59	7.51	6.45	6.12
95	12.82	11.53	10.13	9.80	8.65	7.52	6.52	6.21
96	12.96	11.66	10.20	9.88	8.71	7.53	6.59	6.30

B. Bus Fuel Economy

Calculated fuel economies for transit, intercity and school buses are shown in Table 15. The average for the calculated fuel economy from Table 15 for diesel transit buses for model years 1987 through 1995 is 3.61 mpg. This is reasonably close to the 3.68 mpg for all diesel transit buses in operation in 1994 calculated from data given in the *1996 Transit Fact Book* [5] and therefore seems reasonable.

Table 15. Estimated bus fuel economies (mpg)

Model	Diesel			Gasoline		
Year	Transit	Intercity	School	Transit	Intercity	School
1987	3.43	4.64	6.29	3.11	3.64	6.18
1988	3.47	4.69	6.28	3.15	3.68	6.21
1989	3.51	4.75	6.27	3.19	3.72	6.24
1990	3.55	4.80	6.25	3.22	3.76	6.27
1991	3.59	4.85	6.24	3.26	3.80	6.30
1992	3.63	4.91	6.23	3.30	3.85	6.33
1993	3.67	4.96	6.22	3.33	3.89	6.37
1994	3.71	5.01	6.20	3.37	3.93	6.40
1995	3.75	5.07	6.19	3.40	3.97	6.42
1996	3.79	5.12	6.18	3.44	4.01	6.45

C. Use of Non-Engine Fuel Economy Improvement Devices

For previous versions of MOBILE, projections of conversion factors for future model years were determined by examining increased use estimates of fuel economy improvement devices that were not engine related (aerodynamic devices, drive train optimization, radial tires, speed control and variable speed fan drives). It was thought that if the fuel economy of an engine line improved due to engine improvements (such as better fuel injection control, combustion optimization, turbocharging), these changes would be reflected both in the fuel economy of the vehicle and the BSFC of the engine, and that these effects would more or less offset one another. However, non-engine related fuel economy improvement devices could improve the fuel economy of the vehicle without affecting engine BSFC. Since improving fuel economy without a corresponding reduction in BSFC would decrease conversion factors, these non-engine fuel economy improvement devices could affect conversion factors for future model years and need to be taken into account.

As part of this study, the 1992 TIUS data was used to determine the extent to which non-engine related devices were used by the various weight classes in the U.S. heavy-duty vehicle fleet. Regression analyses were performed on data for model years 1983 through 1992 to determine use trends of these devices and project those trends to the 1996 model year. These devices are the most beneficial on longer-haul, higher speed trips. Therefore, if the number of trucks that use these devices is less than the number of trucks that operate on long-haul trips, one can assume that there may be increased use of these devices in the future, which would affect truck fleet fuel economy and thus conversion factors. To test this assumption, predicted use of non-engine fuel economy improvement devices were compared against the VMT fraction of long-haul trips.

Table 16 shows the percent of use of non-engine fuel economy improvement devices for heavy-duty gasoline trucks. As may be seen in this table, in all classes except 3 and 4, data projected out for 1996 model year trucks shows that, in fact, the use percent of non-engine related devices exceeds the percent of trucks that operate on long-haul trips. Thus, it is unlikely that there will be further increased use of these devices past the 1996 model year and therefore need not be considered in conversion factor calculations for future model years. Since class 3 and 4 vehicles still spend most of their travel in shorter trips, it is not likely that there will be much increased use of these devices in those weight classes over the 1996 model year levels, either.

A similar trend in the use of non-engine related devices is illustrated in Table 17 for 1996 model year heavy-duty diesel trucks. For diesel trucks, however, the percent of use of non-engine fuel economy improvement devices for the 1996 model year greatly exceeds the long-haul travel fraction for all weight classes. Thus, it is unlikely that there will be much further use of non-engine fuel economy improvement devices in diesel trucks beyond those already in use on 1996 model year trucks. Therefore, increased use of these devices need not be figured into calculations of conversion factors beyond the 1996 model year.

Table 16. Estimated percent of use of non-engine fuel economy improvements in each weight class of 1996 model year heavy-duty gasoline vehicles

Weight Class	**2B**	**3**	**4**	**5**	**6**	**7**	**8A**
Long-Haul VMT Fraction	1%	10%	27%	3%	12%	3%	2%
Aero Devices							
TIUS	18%	9%	11%	33%	34%	24%	38%
MOBILE4	0%	0%	0%	7%	7%	7%	7%
Drive Train Optimization							
TIUS	22%	12%	32%	23%	39%	37%	31%
MOBILE4	27%	27%	27%	27%	27%	27%	27%
Radial Tires							
TIUS	96%	100%	77%	73%	100%	86%	91%
MOBILE4	67%	67%	67%	14%	14%	14%	14%
Speed Control							
TIUS	12%	5%	10%	62%	32%	44%	42%
MOBILE4	13%	13%	13%	4%	4%	4%	4%
Fan Drives							
TIUS	18%	9%	18%	26%	10%	25%	15%
MOBILE4	0%	0%	0%	90%	90%	90%	90%

D. Fuel Densities

Fuel densities for unleaded gasoline, taken from the NIPER publications, are shown in Table 18. Fuel densities for #2 diesel are shown in Table 19. These fuel densities are similar to those used in MOBILE4 emission factor calculations [1].

Table 17. Estimated percent of use of non-engine fuel economy improvements in each weight class of 1996 model year heavy-duty diesel vehicles

Weight Class	**2B**	**3**	**4**	**5**	**6**	**7**	**8A**	**8B**
Long-Haul VMT Fraction	5%	12%	8%	16%	11%	23%	57%	74%
Aero Devices								
TIUS	17%	21%	18%	17%	28%	48%	87%	100%
MOBILE4	0%	0%	0%	7%	7%	7%	7%	32%
Drive Train Optimization								
TIUS	30%	40%	38%	56%	46%	59%	80%	100%
MOBILE4	27%	27%	27%	27%	27%	27%	27%	27%
Radial Tires								
TIUS	91%	91%	100%	100%	92%	94%	90%	95%
MOBILE4	67%	67%	67%	14%	14%	14%	14%	50%
Speed Control								
TIUS	39%	28%	41%	35%	41%	41%	71%	81%
MOBILE4	13%	13%	13%	4%	4%	4%	4%	14%
Fan Drives								
TIUS	41%	42%	28%	40%	46%	46%	80%	85%
MOBILE4	0%	0%	0%	90%	90%	90%	90%	100%

Table 18. Gasoline Fuel Densities

	API Gravity			**Density**
Year	**Winter**	**Summer**	**Average**	**lb/gal**
1987	62.3	59.2	60.75	6.130
1988	62.5	58.9	60.70	6.131
1989	61.8	58.2	60.00	6.154
1990	62.2	58.2	60.20	6.147
1991	61.8	58.0	59.90	6.157
1992	61.2	57.4	59.30	6.176
1993	61.2	56.1	58.65	6.197
1994	60.8	55.7	58.25	6.210
1995	59.4	56.1	57.75	6.227
1996	60.2	56.9	58.55	6.201
Average				6.173
MOBILE4				6.09

Table 19. Diesel Fuel Densities

Year	API Gravity	Density lb/gal
1987	34.2	7.112
1988	34.5	7.099
1989	33.8	7.129
1990	34.3	7.107
1991	34.0	7.120
1992	33.7	7.133
1993	34.3	7.107
1994	35.3	7.065
1995	35.4	7.061
1996	35.6	7.052
Average		7.099
MOBILE4		7.11

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APPENDIX

TIHDCF.C

```
/* TIHDCF
   Converts the TIUS dataset TI92MDF.DAT to a comma delimited file for
   importing into dBASE file TIUSHDCF
*/
#include <stdio.h>
#include <ctype.h>

#define comma   44

char buffer[625];
char bufout[110];
FILE *fin,*fout;
int count;
long n;
int idex,odex;

void main()
{
    fin = fopen("E:TI92MDF.DAT","rb");
    fout = fopen("C:TIHDCF1.DAT","wb");
    n = 0;
    while (n < 125000) {
       fgets(buffer,625,fin);
       n++;
       odex = 0;
       idex = 14;
       /* EXPANF    15-21  */
       for (count=1; count <=7; count++) {
          bufout[odex] = buffer[idex];
          odex++;
          idex++;
       }
       bufout[odex] = comma;
       odex++;
       /* MDLYR    24-25  */
       idex = 23;
       for (count=1; count <=2; count++) {
          bufout[odex] = buffer[idex];
          odex++;
          idex++;
       }
       bufout[odex] = comma;
       odex++;
   /* AVGWT  99-104  */
       idex = 98;
       for (count=1; count <=6; count++) {
          bufout[odex] = buffer[idex];
          odex++;
          idex++;
       }
       bufout[odex] = comma;
       odex++;
       /* EngTyp  112  */
       idex = 111;
       bufout[odex] = buffer[idex];
       odex++;
       bufout[odex] = comma;
       odex++;
       /* PKCID   114-115  */
```

```
idex = 113;
for (count=1; count <=2; count++) {
   bufout[odex] = buffer[idex];
   odex++;
   idex++;
}
bufout[odex] = comma;
odex++;
/* AERODN  119  */
idex = 118;
bufout[odex] = buffer[idex];
odex++;
bufout[odex] = comma;
odex++;
/* AXLRAT  120  */
idex++;
bufout[odex] = buffer[idex];
odex++;
bufout[odex] = comma;
odex++;
/* ECOENG  121  */
idex++;
bufout[odex] = buffer[idex];
odex++;
bufout[odex] = comma;
odex++;
/* RADIAL  123  */
idex = 122;
bufout[odex] = buffer[idex];
odex++;
bufout[odex] = comma;
odex++;
/* GOVNOR  124  */
idex++;
bufout[odex] = buffer[idex];
odex++;
bufout[odex] = comma;
odex++;
/* VARFAN  125  */
idex++;
bufout[odex] = buffer[idex];
odex++;
bufout[odex] = comma;
odex++;
/* OTHFUEL  126  */
idex++;
bufout[odex] = buffer[idex];
odex++;
bufout[odex] = comma;
odex++;
/* ANNMIL  155-160 */
idex = 154;
for (count=1; count <=6; count++) {
   bufout[odex] = buffer[idex];
   odex++;
   idex++;
}
bufout[odex] = comma;
odex++;
```

```
      /* MPG 170-172 */
      idex = 169;
      for (count=1; count <=3; count++) {
         bufout[odex] = buffer[idex];
         odex++;
         idex++;
      }
      bufout[odex] = comma;
      odex++;
   /* PLOCAL  183-185 */
      idex = 182;
      for (count=1; count <=3; count++) {
         bufout[odex] = buffer[idex];
         odex++;
         idex++;
      }
      bufout[odex] = comma;
      odex++;
    /* PSHORT  186-188 */
      for (count=1; count <=3; count++) {
         bufout[odex] = buffer[idex];
         odex++;
         idex++;
      }
      bufout[odex] = comma;
      odex++;
     /* PSMED  189-191 */
      for (count=1; count <=3; count++) {
         bufout[odex] = buffer[idex];
         odex++;
         idex++;
      }
      bufout[odex] = comma;
      odex++;
    /* PLMED  192-194 */
      for (count=1; count <=3; count++) {
         bufout[odex] = buffer[idex];
         odex++;
         idex++;
      }
      bufout[odex] = comma;
      odex++;
    /* PLONG  195-197 */
      for (count=1; count <=3; count++) {
         bufout[odex] = buffer[idex];
         odex++;
         idex++;
      }
      bufout[odex] = comma;
      odex++;
      /* TIUGVW  421-422 */
      idex = 420;
      for (count=1; count <=2; count++) {
         bufout[odex] = buffer[idex];
         odex++;
         idex++;
      }
      bufout[odex] = comma;
      odex++;
```

```
      /* PKGVW  423 */
      bufout[odex] = buffer[idex];
      odex++;
      idex++;
      bufout[odex] = comma;
      odex++;
      /* PKRWGT  424-429  */
      for (count=1; count <=6; count++) {
         bufout[odex] = buffer[idex];
         odex++;
         idex++;
      }
      bufout[odex] = '\n';
      odex++;
      bufout[odex] = '\0';
      fputs(bufout,fout);
   }
   fclose(fout);
   puts("\nfile 1 written");
   fout = fopen("C:TIHDCF2.DAT","wb");
   while (fgets(buffer,625,fin)) {
      odex = 0;
      idex = 14;
      /* EXPANF    15-21  */
      for (count=1; count <=7; count++) {
         bufout[odex] = buffer[idex];
         odex++;
         idex++;
      }
      bufout[odex] = comma;
      odex++;
      /* MDLYR    24-25  */
      idex = 23;
      for (count=1; count <=2; count++) {
         bufout[odex] = buffer[idex];
         odex++;
         idex++;
      }
      bufout[odex] = comma;
      odex++;
         /* AVGWT  99-104  */
      idex = 98;
      for (count=1; count <=6; count++) {
         bufout[odex] = buffer[idex];
         odex++;
         idex++;
      }
      bufout[odex] = comma;
      odex++;
      /* EngTyp  112  */
      idex = 111;
      bufout[odex] = buffer[idex];
      odex++;
      bufout[odex] = comma;
      odex++;
      /* PKCID   114-115  */
      idex = 113;
      for (count=1; count <=2; count++) {
         bufout[odex] = buffer[idex];
```

```
      odex++;
      idex++;
   }
   bufout[odex] = comma;
   odex++;
   /* AERODN  119  */
   idex = 118;
   bufout[odex] = buffer[idex];
   odex++;
   bufout[odex] = comma;
   odex++;
   /* AXLRAT  120  */
   idex++;
   bufout[odex] = buffer[idex];
   odex++;
   bufout[odex] = comma;
   odex++;
   /* ECOENG  121  */
   idex++;
   bufout[odex] = buffer[idex];
   odex++;
   bufout[odex] = comma;
   odex++;
   /* RADIAL  123  */
   idex = 122;
   bufout[odex] = buffer[idex];
   odex++;
   bufout[odex] = comma;
   odex++;
   /* GOVNOR  124  */
   idex++;
   bufout[odex] = buffer[idex];
   odex++;
   bufout[odex] = comma;
   odex++;
   /* VARFAN  125  */
   idex++;
   bufout[odex] = buffer[idex];
   odex++;
   bufout[odex] = comma;
   odex++;
   /* OTHFUEL  126  */
   idex++;
   bufout[odex] = buffer[idex];
   odex++;
   bufout[odex] = comma;
   odex++;
   /* ANNMIL  155-160 */
   idex = 154;
   for (count=1; count <=6; count++) {
      bufout[odex] = buffer[idex];
      odex++;
      idex++;
   }
   bufout[odex] = comma;
   odex++;
      /* MPG 170-172 */
      idex = 169;
   for (count=1; count <=3; count++) {
```

```
         bufout[odex] = buffer[idex];
         odex++;
         idex++;
      }
      bufout[odex] = comma;
      odex++;
         /* PLOCAL  183-185 */
         idex = 182;
      for (count=1; count <=3; count++) {
         bufout[odex] = buffer[idex];
         odex++;
         idex++;
      }
      bufout[odex] = comma;
      odex++;
         /* PSHORT  186-188 */
      for (count=1; count <=3; count++) {
         bufout[odex] = buffer[idex];
         odex++;
         idex++;
      }
      bufout[odex] = comma;
      odex++;
         /* PSMED  189-191 */
      for (count=1; count <=3; count++) {
         bufout[odex] = buffer[idex];
         odex++;
         idex++;
      }
      bufout[odex] = comma;
      odex++;
         /* PLMED  192-194 */
      for (count=1; count <=3; count++) {
         bufout[odex] = buffer[idex];
         odex++;
         idex++;
      }
      bufout[odex] = comma;
      odex++;
         /* PLONG  195-197 */
      for (count=1; count <=3; count++) {
         bufout[odex] = buffer[idex];
         odex++;
         idex++;
      }
      bufout[odex] = comma;
      odex++;
      /* TIUGVW  421-422 */
      idex = 420;
      for (count=1; count <=2; count++) {
         bufout[odex] = buffer[idex];
         odex++;
         idex++;
      }
      bufout[odex] = comma;
      odex++;
      /* PKGVW  423 */
      bufout[odex] = buffer[idex];
      odex++;
```

```
       idex++;
       bufout[odex] = comma;
       odex++;
       /* PKRWGT  424-429  */
       for (count=1; count <=6; count++) {
          bufout[odex] = buffer[idex];
          odex++;
          idex++;
       }
       bufout[odex] = '\n';
       odex++;
       bufout[odex] = '\0';
       fputs(bufout,fout);
    }
    fclose(fout);
    puts("\nfile 2 written");
    fclose(fin);
}
```